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On the Classical Model of Nuclear Fission

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1.

THE first experiments on neutron bombardment of various elements carried out by Fermi and his collaborators[1] included the study of the group of activities observed in uranium which were at that time ascribed to transuranic elements. The great number of studies[2] following this first work led finally to the results of Hahn and Strassmann[3] which showed clearly that many of the activities ascribed to transuranic elements came, instead, from nuclei of approximately half the mass of uranium. The startling conclusion that these activities must arise from the splitting of the uranium nucleus under neutron bombardment into two fragment nuclei was pointed out by Meitner and Frisch,[4] and was quickly confirmed by subsequent experiments. In the first theoretical discussion of this new type of nuclear reaction, Meitner and Frisch[4] proposed the name *fission* for the process, and compared it with the splitting that may take place in a liquid drop in oscillation. This model was supported by Bohr[5] who correlated it with other nuclear properties and, at the same time, emphasized how far the phenomenon of nuclear fission may be described classically. A very complete theoretical discussion of both the classical and quantum aspects of fission was given by Bohr and Wheeler,[6] and it is proposed here to describe some of the classical theory of fission developed by these authors.

2.

In this section qualitative arguments from general properties of nuclear forces will be given to justify the classical model used to picture fission. This model is more accurate for the heavier nuclei, but these are the only ones of actual interest because only in the heaviest nuclei is the fission process experimentally accessible.

In the first place, the forces between nuclear particles, neutrons and protons, are known to be of short range; that is, of the order of 2×10^{-13} cm. A heavy nucleus, such as uranium, has a diameter of the order of 18×10^{-13} cm. Thus, it may be said that a heavy nucleus has a fairly well-defined surface. Of course, from a macroscopic point of view, the surface of a nucleus is poorly defined compared with that, for example, of a water droplet, in which the size of the droplet and the range of the forces between component molecules are of entirely different orders of magnitude.

[1] E. Fermi, Nature **133**, 898 (1934); Fermi, Amaldi, D'Agostino, Rasetti and Segrè, Proc. Roy. Soc. **A146**, 483 (1934).

[2] Cf. the review article by L. A. Turner, Rev. Mod. Phys. **12**, 1 (1940).

[3] O. Hahn and F. Strassmann, Naturwiss. **27**, 11 (1939); 27, 89 (1939).

[4] L. Meitner and O. R. Frisch, Nature **143**, 239 (1939); **143**, 471 (1939).

[5] N. Bohr, Nature **143**, 330 (1939); Phys. Rev. **55**, 418 (1939).

[6] N. Bohr and J. A. Wheeler, Phys. Rev. **56**, 426 (1939).

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The second general property of nuclear forces that will be used here is inferred from the following observation: The most important contribution to the binding energy of nuclei increases linearly with the number of component nuclear particles A. If the attractions between nuclear particles were of the type familiar from classical theory—that is, if each particle in the nucleus attracted every other particle in the nucleus—the binding energy would vary as A^2. The simplest interpretation of the observed variation is that there is a *saturation* of nuclear forces. This saturation may be pictured as follows: A neutron most strongly attracts another neutron that is most nearly in the same quantum state (except for spin) as the given neutron; a similar law is considered to hold between neutrons and protons and, aside from their electrostatic repulsion by the Coulomb law, between protons and protons.[7] Saturation arises then in these interactions because the Pauli exclusion principle limits to two the number of particles of a given kind that may be in the same state. There is thus an approximate pairing of neutron-proton interactions with each particle of one kind strongly attracting at most one particle of the same kind, and at most two particles of the second kind. On this basis, one may understand the difference in neutron binding energy between an isotope with an even number of neutrons and one with an odd number. For example, the odd neutron-number uranium isotope ${}_{92}U^{235}$ upon capturing an additional neutron of low energy has greater energy of excitation than the even neutron-number isotope ${}_{92}U^{238}$ upon similar capture; Bohr and Wheeler estimate these excitation energies at 6.4 Mev and 5.2 Mev, respectively.

Saturation implies not only that the binding energy is proportional to the number of particles but also that *nuclear matter has constant density* from nucleus to nucleus and in a given nucleus. Thus, in a nucleus of radius R, the average number of particles per unit volume is $\delta = \text{const.} = A/(4\pi/3)R^3$. Consequently, one should have $R \propto A^{\frac{1}{3}} = r_0 A^{\frac{1}{3}}$. This dependence of R on the number of component nuclear particles A is verified experimentally, and r_0 is found to be approximately 1.48×10^{-13} cm. The total nuclear charge Ze also is taken to be uniformly distributed throughout the nuclear volume, so that the electrostatic energy of the nucleus is that of a uniformly charged sphere of the radius R, namely, $(3/5)(Ze)^2/R$. It is reasonable to assume that there should be no appreciable tendency for the protons to concentrate near the nuclear boundary since nuclear attractions are larger than the electrostatic repulsion operating between protons.

At the boundary of a nucleus there occurs a special effect, namely, the *desaturation* of the nuclear short range binding forces. This desaturation may be described by saying that the surface of the nucleus is under tension in analogy with the desaturation taking place at the boundary of a liquid drop which is similarly described by a surface tension. Because of the constant volume density of nuclei, any deformation of a nucleus must be considered as taking place at constant volume. Consequently, the energy of the nuclear binding forces acting in the volume of the nucleus remains constant with change of shape, and the only changes of energy which need be considered are in the surface energy and in the electrostatic energy. In summary, it may be said that the approximate model taken for a heavy nucleus is *a uniformly charged, incompressible, fluid sphere under surface tension.*

To get an idea of the orders of magnitude of the energies mentioned, one may refer to an approximate, "semiempirical" formula[8] for the total binding energy of a nucleus of mass M containing N neutrons, each of mass M_n, and Z protons, each of mass M_p,

$$NM_n + ZM_p - M = \alpha A - 4\pi r_0^2 A^{\frac{1}{3}} O - (3/5)(Ze)^2/r_0 A^{\frac{1}{3}} - \beta(N-Z)^2/A. \quad (1)$$

The first term in the right-hand member of Eq. (1) is the main contribution to the binding energy and arises from the saturation or volume forces; the second term represents a decrease in stability caused by surface desaturation, or "surface tension"; the third term is a decrease in stability arising from an

[7] This picture is inaccurate inasmuch as it is not found possible to assign a state to each particle independently of the remaining particles. A more correct description leads to similar qualitative conclusions.

[8] H. A. Bethe and R. F. Bacher, Rev. Mod. Phys. 8, 165 (1936).

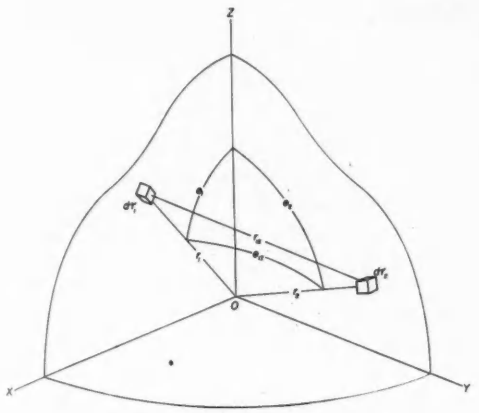

FIG. 1. Coordinates used in the calculation of nuclear electrostatic energy.

excess in the number of neutrons over the number of protons. For $_{92}U^{239}$, $\alpha A \approx 3300$ Mev; $4\pi R^2 O = 4\pi r_0^2 A^{\frac{1}{3}} O \approx 540$ Mev; $(3/5)(Ze)^2/R \approx 800$ Mev; $\beta(N-Z)^2/A \approx 250$ Mev.

If a nucleus of mass M splits into smaller parts of masses M_1, M_2, $\cdots$, the total energy released is, according to the relativistic mass-energy formula, $E = Mc^2 - \sum M_i c^2$, where the original nucleus and the resulting nuclei are unexcited and at rest. The splitting of a heavy nucleus into, for example, two fragments of approximately the same size leads to an abnormally high mass-to-charge ratio so that the mass energies of the fragments lie outside the ordinary range which has been measured directly. The excess neutron content of the fragments will be reduced by β-emission and some neutron emission. A detailed estimate[6] of the mass energy of such fragments as would arise from fission leads to the conclusion that splitting is exothermic for nuclei with values of A larger than about 100; for uranium the energy released from division into two nearly equal fragments is, on the basis of this estimate, of the order of 200 Mev.[9]

A very rough estimate of the fission energy release may be made using Eq. (1). The values of the constants in this equation are taken to be: $\alpha = 13.9$ Mev; $4\pi r_0^2 \sigma_0 = 14$ Mev; $(3/5)e^2/r_0 = 0.59$ Mev; $\beta = 19.5$ Mev. If one assumes the fission reaction

$$_{92}U^{239} \rightarrow {}_{46}Pd^{119} + {}_{46}Pd^{120},$$

and calculates by Eq. (1) the difference between the initial and final mass energies for this case, the terms in α and β cancel. The energy release ΔE is then the difference between the initial and final values for the surface and Coulomb energies,

$$E = 4\pi r_0^2 A^{\frac{1}{3}} O - 2 \cdot 4\pi r_0^2 (A/2)^{\frac{1}{3}} O + (3/5)(e^2/r_0) Z^2/A^{\frac{1}{3}} - 2(3/5)(e^2/r_0)(Z/2)^2/(A/2)^{\frac{1}{3}},$$

which is here $\sim$160 Mev. The nuclei $_{46}Pd^{119}$ and $_{46}Pd^{120}$ would be unstable because of their excess neutron content and would presumably go over into the stable nuclei $_{50}Sn^{119}$ and $_{50}Sn^{120}$, respectively. The mass energy difference between $_{92}U^{239}$ and the latter nuclei gives from Eq. (1) the same surface energy loss as before, a slightly smaller Coulomb energy gain, and a gain from the terms in β with a resulting total energy release in the fission to the final products of the order of 180 Mev.

If the values of the nuclear constants assumed here are used, it will be shown in Sec. 3 that, while fission is energetically possible, all the nuclei, including the uranium isotopes, are stable when unexcited. This stability persists even in the nuclei with the largest values of Z because the decrease in electrostatic energy in a *small* deformation from the spherical shape is overcompensated by the increase in surface energy arising from the increase in exposed nuclear surface.

3.

The deformation of a nucleus initially a sphere of radius R may be specified by giving the magnitude of the radius vector from the center of mass to the boundary. If the deformed nucleus is taken to have zonal symmetry—that is, if its boundary is a surface of revolution—this radius vector will be independent of the azimuthal angle φ, and will be determined only by the colatitude θ. In this case the radius vector to the boundary, $r(\theta)$, may be expressed as a sum of Legendre polynomials,

$$\begin{aligned} r(\theta) &= R\{1 + \alpha_0 + \alpha_1 P_1(\cos\theta) + \alpha_2 P_2(\cos\theta) + \cdots\} \\ &= R\{1 + \alpha_0 + Q(\cos\theta)\}. \end{aligned} \tag{2}$$

[9] Experimental value measured by M. C. Henderson, Phys. Rev. [58, 774 (1940)] is $\sim$180 Mev. See also M. H. Kanner and H. H. Barschall, Phys. Rev. 57, 372 (1940).

The Legendre polynomials have their usual values so that

$$\int_0^\pi P_n^2(\cos\theta)\sin\theta d\theta = 2/(2n+1); \quad \int_0^\pi P_m(\cos\theta)P_n(\cos\theta)\sin\theta d\theta = 0, \ (n \neq m).$$

For stability considerations, the energy need be calculated only for small deformations, and terms containing α's with powers higher than the second will be neglected. In this approximation, the limitation of zonal symmetry in the deformation is unessential; the most general deformation, which would be expressed in terms of surface harmonics, leads to the same energy expressions. The requirement that the volume be unchanged determines α_0:

$$4\pi R^3/3 = \int_0^{2\pi} d\varphi \int_0^\pi \sin\theta d\theta \int_0^{r(\theta)} r^2 dr,$$

from which one finds in the present approximation,

$$\alpha_0 = -\sum_{n=1} \alpha_n^2/(2n+1) = -K. \tag{3}$$

The surface energy E_S of the deformed nucleus is given by the product of the surface tension O and the total area, or

$$E_S = O\int dS, \tag{4}$$

where, since $r(\theta)$ is independent of φ,

$$\begin{aligned} dS &= r^2(\theta)\sin\theta d\theta d\varphi[1+(dr/rd\theta)^2]^{\frac{1}{2}}, \\ &\approx r^2(\theta)\sin\theta d\theta d\varphi + (\tfrac{1}{2})(dr/d\theta)^2 \sin\theta d\theta d\varphi + \cdots. \end{aligned} \tag{5}$$

One may separate E_S into two terms, E'_S and E''_S, corresponding to these two terms in Eq. (5) for dS. Then

$$\begin{aligned} E'_S &= 2\pi R^2 O\int_0^\pi (1+\alpha_0+Q)^2 \sin\theta d\theta \\ &\approx 4\pi R^2 O\{(1+\alpha_0)^2+K\} \\ &\approx 4\pi R^2 O(1-K). \end{aligned} \tag{4a}$$

For the second term, one has

$$E''_S = \pi R^2 O\int_0^\pi \{\sum_{n=1} \alpha_n^2 (dP_n/d\theta)^2 + \sum_{n\neq m} \alpha_n\alpha_m (dP_n/d\theta)(dP_m/d\theta)\}\sin\theta d\theta.$$

Since $dP_n/d\theta = -\sin\theta dP_n/d(\cos\theta)$, and since

$$\int_0^\pi (dP_n/d(\cos\theta))(dP_m/d(\cos\theta))\sin^3\theta d\theta = n(n+1)\int_0^\pi P_n(\cos\theta)P_m(\cos\theta)\sin\theta d\theta,$$

one has

$$E''_S = 2\pi R^2 O\sum_{n=1} \alpha_n^2 n(n+1)/(2n+1). \tag{4b}$$

Thus,

$$E_S = 4\pi R^2 O\{1+\sum_{n=1} \alpha_n^2 (n-1)(n+2)/2(2n+1)\}. \tag{6}$$

The electrostatic energy E_E may also be determined by a straightforward calculation.[10] As the

[10] For a computation of the surface and electrostatic energies along somewhat different lines, see J. Frenkel, J. Phys. U.S.S.R. 1, 125 (1939).

electric charge density $\rho = Ze/(4\pi R^3/3)$ is constant, one may write

$$E_E = \tfrac{1}{2}\rho^2 \int\int d\tau_1 d\tau_2 / r_{12}, \tag{7}$$

where $d\tau_1$ and $d\tau_2$ are elements of volume at the points $(r_1, \theta_1, \varphi_1)$, $(r_2, \theta_2, \varphi_2)$ within the nucleus, and r_{12} is the distance between them (Fig. 1). If the electrostatic potential of the charge distribution at an interior point $(r_1, \theta_1, \varphi_1)$ is denoted by $\rho V(r_1, \theta_1)$, then

$$V(r_1, \theta_1) = \int d\tau_2 / r_{12}, \tag{8}$$

and

$$E_E/\tfrac{1}{2}\rho^2 = \int V(r_1, \theta_1) d\tau_1. \tag{9}$$

To calculate $V(r_1, \theta_1)$, one may use the following expressions for $1/r_{12}$:

$$1/r_{12} = \sum_{k=0}^{\infty} (r_2^k / r_1^{k+1}) P_k(\cos\theta_{12}), \quad r_2 < r_1; \tag{10a}$$

$$= \sum_{k=0}^{\infty} (r_1^k / r_2^{k+1}) P_k(\cos\theta_{12}), \quad r_2 > r_1. \tag{10b}$$

Then,

$$V(r_1, \theta_1) = \int\int \sin\theta_2 d\theta_2 d\varphi_2 \int_0^{r_1} r_2^2 dr_2 / r_{12} + \int\int \sin\theta_2 d\theta_2 d\varphi_2 \int_{r_1}^{r(\theta_2)} r_2^2 dr_2 / r_{12}. \tag{11}$$

In Eq. (11) the integration over r_2 is divided into these two ranges, since in the first range one must use Eq. (10a) and in the second (10b):

$$V(r_1, \theta_1) = \int\int d\omega_2 \sum_{k=0}^{\infty} P_k(\cos\theta_{12}) / r_1^{k+1} \int_0^{r_1} r_2^{k+2} dr_2 + \int\int d\omega_2 \sum_{k=0}^{\infty} r_1^k P_k(\cos\theta_{12}) \int_{r_1}^{r(\theta_2)} dr_2 / r_2^{k-1}.$$

The integration over dr_2 gives

$$V(r_1, \theta_1) = \sum_{k=0}^{\infty} r_1^2/(k+3) \int\int d\omega_2 P_k(\cos\theta_{12}) + \sum_{k\neq 2} r_1^k/(-k+2) \int\int d\omega_2 P_k(\cos\theta_{12}) (r(\theta_2))^{-k+2}$$

$$- \sum_{k\neq 2} r_1^2/(-k+2) \int\int d\omega_2 P_k(\cos\theta_{12}) + \int\int d\omega_2 P_2(\cos\theta_{12}) r_1^2 \ln (r(\theta_2)/r_1). \tag{12}$$

In Eq. (12), the first and third integrals may be evaluated by using the expansion

$$P_k(\cos\theta_{12}) = \sum_{m=-k}^{+k} \frac{(k-m)!}{(k+m)!} P_k^m(\cos\theta_1) P_k^m(\cos\theta_2) e^{im(\varphi_1 - \varphi_2)}. \tag{13}$$

The integration over ϕ_2 gives a nonzero contribution only for $m = 0$; and the integration over θ_2 gives a nonzero contribution only for $k = 0$. Thus

$$V(r_1, \theta_1) = (4\pi/3) r_1^2 - 2\pi r_1^2 + \sum_{k\neq 2} r_1^k/(-k+2) \int\int d\omega_2 P_k(\cos\theta_{12}) R^{-k+2} (1 + \alpha_0 + Q(\cos\theta_2))^{-k+2}$$

$$+ \int\int d\omega_2 P_2(\cos\theta_{12}) r_1^2 \ln \{(R/r_1)(1 + \alpha_0 + Q(\cos\theta_2))\};$$

$$= -(2\pi/3)r_1^2 + R^2 \sum_{k\neq 2} (r_1/R)^k (1+\alpha_0)^{-k+2}/(-k+2) \int\int d\omega_2 P_k(\cos\theta_{12})$$

$$\times \left\{ 1 + \frac{(-k+2)}{1+\alpha_0} Q + \frac{(-k+2)(-k+1)}{2(1+\alpha_0)^2} Q^2 + \cdots \right\}$$

$$+ \int\int d\omega_2 P_2(\cos\theta_{12}) r_1^2 \left\{ \ln\left((1+\alpha_0)R/r_1\right) + \frac{Q}{1+\alpha_0} - \frac{Q^2}{2(1+\alpha_0)^2} + \cdots \right\};$$

$$\approx -(2\pi/3)r_1^2 + R^2 \sum_{k\neq 2} (r_1/R)^k (1+\alpha_0)^{-k+2}/(-k+2) \int\int d\omega_2 P_k(\cos\theta_{12})$$

$$+ \int\int d\omega_2 P_2(\cos\theta_{12}) r_1^2 \ln\left((1+\alpha_0)R/r_1\right)$$

$$+ R^2 \sum_{k=0}^{\infty} (r_1/R)^k (1+\alpha_0)^{-k+1} \int\int d\omega_2 P_k(\cos\theta_{12}) Q(\cos\theta_2)$$

$$+ R^2 \sum_{l=0}^{\infty} (r_1/R)^k (1+\alpha_0)^{-k} (-k+1)/2 \int\int d\omega_2 P_k(\cos\theta_{12}) Q^2(\cos\theta_2).$$

If one substitutes from Eq. (13) for $P_k(\cos\theta_{12})$ in this last expression, it is evident that in all the integrals the only nonzero contribution from the integration over ϕ_2 is for $m=0$; the first set of integrals is also nonzero only for $k=0$, and the second integral vanishes. The remaining integrals are of the form

$$I = 2\pi R^2 \sum_{k=0}^{\infty} (r_1/R)^k (1+\alpha_0)^{-k+1} P_k(\cos\theta_1) \int_0^{\pi} \sin\theta_2 d\theta_2 P_k(\cos\theta_2) \sum_{n=1} \alpha_n P_n(\cos\theta_2);$$

$$I' = \pi R^2 \sum_{k=0}^{\infty} (r_1/R)^k (1+\alpha_0)^{-k} (-k+1) P_k(\cos\theta_1) \int_0^{\pi} \sin\theta_2 d\theta_2 P_k(\cos\theta_2)$$

$$\times \{ \sum_{n=1} \alpha_n^2 P_n^2(\cos\theta_2) + \sum_{n\neq m} \alpha_n \alpha_m P_n(\cos\theta_2) P_m(\cos\theta_2) \}.$$

Thus

$$I = 4\pi R^2 \sum_{n=1} (r_1/R)^n \frac{(1+\alpha_0)^{-n+1}}{(2n+1)} \alpha_n P_n(\cos\theta_1);$$

and I' may be expressed in terms of the constants,

$$c_{knm} = \int_0^{\pi} \sin\theta_2 d\theta_2 P_k(\cos\theta_2) P_n(\cos\theta_2) P_m(\cos\theta_2), \qquad \begin{matrix} k=0, 1, 2, \cdots \\ n, m=1, 2, \cdots. \end{matrix}$$

It may be noted that $c_{onm}=0$ for $n\neq m$, and $c_{onn}=2/(2n+1)$. In terms of the c's,

$$I' = \pi R^2 \sum_{k=0}^{\infty} (r_1/R)^k (1+\alpha_0)^{-k} (-k+1) P_k(\cos\theta_1) \{ \sum_{n=1} \alpha_n^2 c_{knn} + \sum_{n\neq m} \alpha_n \alpha_m c_{knm} \}.$$

Upon collecting these results, one gets for $V(r_1, \theta_1)$,

$$V(r_1, \theta_1) \approx -(2\pi/3)r_1^2 + 2\pi R^2 (1+\alpha_0)^2 + 4\pi R^2 \sum_{n=1} (r_1/R)^n \frac{(1+\alpha_0)^{-n+1}}{(2n+1)} \alpha_n P_n(\cos\theta_1)$$

$$+ \pi R^2 \sum_{k=0}^{\infty} (r_1/R)^k (1+\alpha_0)^{-k} (-k+1) P_k(\cos\theta_1) \{ \sum_{n=1} \alpha_n^2 c_{knn} + \sum_{n\neq m} \alpha_n \alpha_m c_{knm} \}. \quad (14)$$

Integration of $V(r_1, \theta_1)$ over the volume of the deformed nucleus determines the total electrostatic energy. Terms containing α_0 in powers higher than the first are dropped, as are terms containing the α_n's in powers higher than the second. Thus, from the first term on the right-hand side of (14), one has

$$-(2\pi/3)\int_0^{2\pi} d\varphi_1 \int_0^{\pi} \sin\theta_1 d\theta_1 \int_0^{r(\theta_1)} r_1^4 dr_1 \approx -(8\pi^2/15)R^5(1+5K);$$

from the second term,

$$2\pi R^2(1+\alpha_0)^2 \cdot 4\pi R^3/3 \approx 8\pi^2 R^5(1-2K)/3;$$

from the third term,

$$4\pi R^5 \sum_{n=1} \frac{\alpha_n}{(2n+1)} \frac{(1+\alpha_0)^{-n+1}}{(n+3)} \int\int d\omega_2 (1+\alpha_0+Q(\cos\theta_1))^{n+3} P_n(\cos\theta_1) \approx 16\pi^2 R^5 \sum_{n=1} \alpha_n^2/(2n+1)^2;$$

and from the fourth term,

$$\pi R^5 \sum_{k=0}^{\infty} (1+\alpha_0)^{-k} \frac{(-k+1)}{(k+3)} \{\sum_{n=1} \alpha_n^2 c_{knn} + \sum_{n\neq m} \alpha_n \alpha_m c_{knm}\} \int\int d\omega_1 (1+\alpha_0+Q)^{k+3} P_k(\cos\theta_1)$$

$$\approx 4\pi^2 R^5/3 \{\sum_{n=1} \alpha_n^2 c_{onn} + \sum_{n\neq m} \alpha_n \alpha_m c_{onm}\},$$

since only the term $k=0$ contributes in the present approximation. Because of the values for c_{onm}, this last term is equal to

$$(8\pi^2 R^5/3) \sum_{n=1} \alpha_n^2/(2n+1).$$

Addition of these terms gives

$$E_E/\tfrac{1}{2}\rho^2 = (16\pi^2 R^5/3)\{2/5 - \sum_{n=1} \alpha_n^2/(2n+1)[1-3/(2n+1)]\}. \tag{15}$$

The final result for the electrostatic energy in the present approximation may be expressed from Eq. (15) as

$$E_E = 3(Ze)^2/5R\{1 - 5\sum_{n=1} \alpha_n^2(n-1)/(2n+1)^2\}. \tag{16}$$

It may be noted that α_1 makes no contribution either to E_E or to E_S; this result is to be expected since the term $\alpha_1 P_1(\cos\theta)$ in Eq. (2) corresponds approximately to a translation of the nucleus without deformation.

It is now possible to discuss nuclear stability conditions from Eqs. (6) and (16). In order that a nucleus be stable for small deformations, the potential energy difference $E_S + E_E - 4\pi R^2 O - (3/5)(Ze)^2/R = \Omega$ should be positive. Now

$$\Omega = \sum_{n=2} \alpha_n^2(n-1)/(2n+1)\{4\pi R^2 O(n+2)/2 - [3(Ze)^2/5R]5/(2n+1)\}. \tag{17}$$

It is clear from Eq. (17) that the stability limit is lower for the deformation characterized by $n=2$ than for any other; hence one may assume that the term with $n=2$ gives the critical stability limit:

$$4\pi R^2 O \cdot 2 - (3/5)(Ze)^2/R > 0; \tag{18}$$

or, using the relation $R = r_0 A^{\frac{1}{3}}$, that

$$Z^2/A < 2 \cdot 4\pi r_0^2 O/(3/5)(e^2/r_0). \tag{19}$$

The right-hand side of Eq. (19) may be regarded as giving the limiting value for Z^2/A; if the values for r_0 and O given in the preceding section are used,

$$(Z^2/A)_{\text{lim}} = 2 \cdot 4\pi r_0^2 O/(3/5)(e^2/r_0) \approx 47.5. \tag{20}$$

The largest values of Z^2/A occur in the heaviest nuclei, but even for these, Z^2/A is less than the limiting value. For $_{92}U^{235}$, $Z^2/A = 36.0$; for

$_{92}U^{238}$, $Z^2/A=35.6$; for $_{90}Th^{232}$, $Z^2/A=34.9$. *All the nuclei are thus stable for small deformations, and spontaneous fission cannot be expected to take place.*

While the potential energy function $\Omega(\alpha_2, \alpha_3, \cdots)$ has a minimum at $\alpha_2=\alpha_3=\cdots=0$, it has other minimums for a sufficiently heavy nucleus at other values of the α's corresponding to a configuration in which the nucleus is divided into two fragments. These minimums are much lower than $\Omega(0, 0, \cdots)$, as was shown in Sect. 2 where the large energy release following fission was discussed. In principle, it is possible to calculate $\Omega(\alpha_2, \alpha_3, \cdots)$ for large as well as small values of the α's, and such a calculation would determine the course of the function Ω between the spherical undisturbed state and a state of division. Although approximate determinations of Ω have been made for large deformations,[6,11] the discussion here will be only qualitative. If one pictures a series of deformations with amplitudes increasing toward, say, a dumbbell shape, it is clear that the potential energy function Ω will increase until some critical deformation is reached in which there is an instability; that is, the potential energy would be decreased either by approaching the configuration of division or by a return to the neighborhood of the spherical shape. In this critical configuration the work required for a small deformation in either "direction" vanishes in the first order. There is thus on the potential energy hypersurface, $\Omega(\alpha_2, \alpha_3, \cdots)$, a smooth-topped ridge between the valley at $\alpha_2=\alpha_3=\cdots=0$, and a valley at some configuration $\alpha_2=\alpha_2'$, $\alpha_3=\alpha_3'$, etc., corresponding to a divided nucleus (Fig. 2). The lowest point on such a ridge determines the *minimum* energy input necessary to arrive at the divided configuration. If this configuration occurs for $\alpha_2=\alpha_2^f$, $\alpha_3=\alpha_3^f$, etc., this minimum energy increment will be $E_f=\Omega(\alpha_2^f, \alpha_3^f, \cdots)$. E_f is the characteristic critical energy for the fission process and will be a function of the ratio $(Z^2/A)/(Z^2/A)_{\text{lim}}=x$; as x approaches unity, $E_f(x)$ will decrease monotonically toward zero.

A simple possible mechanism for getting excitation in a heavy nucleus over the critical limit $E_f(x)$ is neutron capture. In uranium it was found experimentally that fission was produced by the capture of neutrons of negligible energy (neutrons of thermal energy $\sim$0.02 ev), and also by the capture of neutrons of high energy. Uranium has three isotopes, $_{92}U^{234}$, $_{92}U^{235}$ and $_{92}U^{238}$, with these abundance ratios:[12] $U^{234}/U^{238}=1/17{,}000$; $U^{235}/U^{238}=1/139$. Since the isotope $_{92}U^{234}$ is present in such a small amount, it cannot be expected to contribute appreciably to the fission reactions. In a theoretical analysis of the experimental situation, it was predicted by Bohr[5] that the fission in uranium with thermal neutrons came from neutron capture by the isotope $_{92}U^{235}$ and that the important contribution to the fission with energetic neutrons came from neutron capture by $_{92}U^{238}$. This theoretical analysis was confirmed by experiments with small samples of the *separated* isotopes.[13] It was pointed out in Sect. 2 that the slow neutron capture reactions,

$$_{92}U^{235}+{}_0n^1\rightarrow{}_{92}U^{236},$$
$$_{92}U^{238}+{}_0n^1\rightarrow{}_{92}U^{239},$$

give an excitation energy in $_{92}U^{236}$ of about 6.4 Mev, while in $_{92}U^{239}$ the excitation is about 5.2 Mev. It therefore appears that $_{92}U^{236}$, for which $x=0.75_5$, has $E_f<6.4$ Mev. It also appears that $_{92}U^{239}$, for which $x=0.74_6$, has $E_f>5.2$ Mev. The minimum neutron bombarding energy that gives fission in $_{92}U^{239}$ has been measured[14] to be 0.35

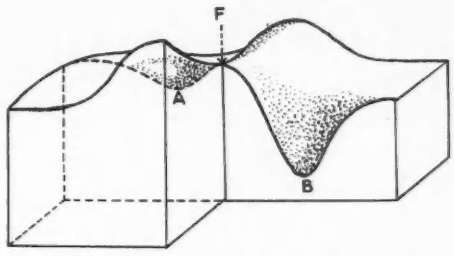

FIG. 2. Diagrammatic sketch of the potential energy surface, illustrating the potential barrier between the configuration A, which corresponds to the undistorted spherical shape of the nucleus, and configuration B, which corresponds to a state of division into two fragments. The point F indicates the saddle point on the barrier between A and B.

[11] R. D. Present and J. K. Knipp, Phys. Rev. **57**, 751 (1940); **57**, 1188 (1940).

[12] A. O. Nier, Phys. Rev. **55**, 150 (1939).

[13] Nier, Booth, Dunning and Grosse, Phys. Rev. **57**, 748 (1940); Kingdon, Pollock, Booth and Dunning, Phys. Rev. **57**, 749 (1940).

[14] Haxby, Shoupp, Stephens and Wells, Phys. Rev. **58**, 199 (1940).

Mev±0.10 Mev. It follows that E_f for $_{92}U^{239}$ is approximately 5.5 Mev. Fission has also been observed when thorium is bombarded with sufficiently energetic neutrons. When the thorium isotope $_{90}Th^{232}$ captures a slow neutron, the excitation energy is estimated at 5.2 Mev.[6] The threshold neutron energy in thorium has been measured[15] to be 1.1±0.10 Mev. Thus E_f for $_{90}Th^{233}$ is approximately 6.3 Mev; the corresponding value of x is 0.73.

4.

The preceding considerations have referred only to the potential energy changes in nuclear deformations. One may also readily calculate the kinetic energy of the oscillations accompanying these deformations. For an incompressible fluid in irrotational motion, the velocity $\mathbf{v}$ at any point in the fluid is derivable from a potential, $\mathbf{v}=\text{grad}\,\psi$. The velocity potential ψ satisfies the Laplace equation, $\Delta\psi=0$. The *mass* density in the nucleus is constant, and, if it is denoted by d, the total kinetic energy will be

$$T=\tfrac{1}{2}d\int\int\int_V(\text{grad}\,\psi)^2\mathrm{d}\tau.$$

From the identity, $(\text{grad}\,\psi)^2\equiv\text{div}\,(\psi\,\text{grad}\,\psi)-\psi\Delta\psi=\text{div}\,(\psi\,\text{grad}\,\psi)$, one sees that the volume integral may be transformed into a surface integral over the nuclear boundary. For small oscillations, the boundary may be approximated by the undeformed surface, that is, the surface of a sphere of radius R. Thus

$$T\approx\tfrac{1}{2}dR^2\int_0^{2\pi}\int_0^{\pi}\psi(\partial\psi/\partial r)_{r=R}\sin\theta\mathrm{d}\theta\mathrm{d}\varphi. \quad (21)$$

It is clear that for deformations with zonal symmetry ψ will be expressible as a sum of zonal harmonics,

$$\psi=\beta_0+\beta_1rP_1(\cos\theta)+\beta_2r^2P_2(\cos\theta)+\cdots+\beta_nr^nP_n(\cos\theta)+\cdots; \quad (22)$$

and

$$\partial\psi/\partial r=\sum_{n=0}n\beta_nr^{n-1}P_n(\cos\theta). \quad (22a)$$

Therefore,

$$T=\tfrac{1}{2}d\sum_{m,n}nR^{n+m+1}\beta_n\beta_m\int_0^{2\pi}\int_0^{\pi}P_mP_n\sin\theta\mathrm{d}\theta\mathrm{d}\theta,$$
$$=2\pi d\sum_n n/(2n+1)R^{2n+1}\beta_n^2. \quad (22b)$$

Now

$$r=R\{1+\alpha_0+\sum_{n=2}\alpha_nP_n(\cos\theta)\}$$

so that, in the first approximation in the α's, the radial velocity $\dot{r}[\equiv\mathrm{d}r/\mathrm{d}t]$ is given by

$$\dot{r}=R\sum_{n=2}\dot{\alpha}_nP_n(\cos\theta). \quad (23)$$

A comparison of Eqs. (23) and (22a) determines the unknown coefficients β_n: $\beta_n=\dot{\alpha}_n/nR^{n-2}$; and the kinetic energy becomes

$$T=2\pi dR^5\sum_{n=2}\dot{\alpha}_n^2/n(2n+1).$$

If one neglects the small difference between the masses of the proton and neutron and writes $M_n\approx M_p=M$, then $d=MA/(4\pi R^3/3)$ and

$$T=(3/2)MAR^2\sum_{n=2}\dot{\alpha}_n^2/n(2n+1)$$
$$=(3/2)MA^{5/3}r_0^2\sum_{n=2}\dot{\alpha}_n^2/n(2n+1). \quad (24)$$

From Eqs. (17) and (24) one sees that, in the present approximation, there is no coupling between the modes of oscillation; the total energy is a sum of the form

$$\sum_{n=2}(T_n+\Omega_n).$$

Each mode of oscillation has the energy form of a simple harmonic oscillator. If momentums p_n canonically conjugate to the generalized coordinates α_n are introduced,

$$p_n=\partial T/\partial\dot{\alpha}_n=3MA^{5/3}r_0^2\dot{\alpha}_n/n(2n+1),$$

the energy of each mode may then be expressed in Hamiltonian form,

$$H_n=(1/2m_n)p_n^2+(k_n^2/2)\alpha_n^2. \quad (25)$$

From Eq. (24),

$$m_n=\frac{3}{n(2n+1)}MA^{5/3}r_0^2,$$

and from (Eq. 17),

$$k_n=\frac{2(n-1)}{(2n+1)}4\pi r_0^2A^{\frac{1}{3}}O\{(n+2)/2-10x/(2n+1)\},$$

[15] Haxby, Shoupp, Stephens and Wells, Phys. Rev. **57**, 1088 (1940).

where, as before, $x=(Z^2/A)/(Z^2/A)_{\text{lim}}$. The angular frequency ω_n of the nth mode of oscillation is $(k_n/m_n)^{\frac{1}{2}}$.

It should be pointed out that the calculations given here are similar to those carried out by Rayleigh in his study of the oscillations of water droplets in jets.[16] The only essential difference between the calculations for the nuclear problem and those for the water droplet is that an electrostatic charge on a droplet is distributed uniformly over the surface, whereas for the nucleus it is distributed uniformly through the volume. There is also for charged water droplets a stability limit, which determines the fineness of the jet.

It may be of interest to remark that the potential energy of deformation and the kinetic energy of oscillation may be calculated in a somewhat different way from that presented in Secs. 3 and 4. One need only determine the electrostatic potential at the surface in the first approximation in the α_n's. The pressure at the surface is also calculated in the first approximation from the expression $p=O(1/R_1+1/R_2)$. The total curvature $(1/R_1+1/R_2)$ is readily found.[17] From the expressions for the pressure and the electrostatic potential at the surface, the change in potential energy due to deformation is determined. The frequencies of oscillation are found from the hydrodynamical relation $p/d=-\partial\psi/\partial t-V(r(\cos\theta),\theta)+\text{const}$. These calculations are carried out as readily for distortions expressed in terms of surface harmonics as for those limited to zonal symmetry.

So far the discussion of nuclear stability and fission has been purely classical, and the classical description must be justified by consideration of the quantum aspects of the problem. It is clear from Eq. (25) that each mode of oscillation has the quantum-mechanical behavior of a simple harmonic oscillator with its characteristic zero-point energy and zero-point oscillations. In order to describe classically deformations of the order of magnitude of nuclear dimensions, the amplitude of the zero-point oscillations must be appreciably smaller than the nuclear radius. If the mean square amplitude of the zero-point oscillation for the nth mode is denoted by $\langle\alpha_n^2\rangle_{\text{zero point}}$, then one finds readily that

$$\langle\alpha_n^2\rangle_{\text{zero point}}=\hbar/2(m_nk_n)^{\frac{1}{2}},$$

which is indeed small compared with R^2. The zero-point energy is $E_n=(\frac{1}{2})\hbar\omega_n=(\frac{1}{2})\hbar(k_n/m_n)^{\frac{1}{2}}$; in particular, for $n=2$, one finds in uranium $E_2\sim 0.4$ Mev. This zero-point energy is small compared with the energy E_f which is about 5 Mev. Hence, one may also describe the critical deformations in the neighborhood of $\alpha_n=\alpha_n^f$ that lead to fission, in a classical way.

[16] *Theory of Sound*, ed. 2, Vol. II, §364; Phil. Mag. **14**, 184 (1882).

[17] Lamb, *Hydrodynamics*, ed. 6, §275.

Presentation of the Concept of Liquid Structure

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AND

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ALTHOUGH it is an easy matter to present to students the structure of an idealized crystal with its regularly arranged atoms and it is not a difficult task to visualize the complete lack of structure in a gas, the description of the arrangement of atoms in a liquid has suffered because it is an intermediate case. This lack of adequate description for the "structure" of a liquid has been alleviated by recent work on the diffraction of x-rays by liquids. Since x-rays have served very effectively in investigating the arrangements of atoms in crystals and the distributions of atoms in monatomic gases, it is reasonable to look to them for a description of the arrangement of atoms in a liquid. X-ray diffraction studies lead to the determination of the distribution of atoms about a given atom (for an element) in the solid, liquid or gaseous state, and this atomic distribution curve is characteristic of the state of the material. Hence the atomic distribution curve can be used to present the concept of the "structure" of matter in any state. In the case of liquids, this, perhaps, is the most quantitative expression of "structure" that can be given.

To illustrate the idea of atomic distribution, consider a regular square array of atoms in a plane as shown in Fig. 1. Assuming an ideal

array—that is, one for which there is no heat motion of the atoms—the atomic distribution can be found from geometric consideration of the neighbors surrounding any given atom. Take atom O as origin and count the neighbors at various distances. The four nearest neighbors are all at the same distance a from O. There are also four at a distance $\sqrt{2}a$, four at $2a$, eight at $\sqrt{5}a$ and so on. This idealized distribution is shown by the vertical lines in Fig. 2. If the atoms are not at rest, but partake of heat motion, then this idealized structure, or distribution curve, will be smeared out, and, according to the kinetic picture, the amount of smearing out will depend in some way on the temperature of the assemblage. If the temperature is increased sufficiently, melting will occur and the smearing out will be greater than that for the material in the solid form. However, if the density of the liquid phase is almost equal to that of the solid, it is unlikely that the distribution curve for the liquid will be entirely different from that of the solid just under the melting point. Prins and Petersen[1] have arrived at an expression which they used for smearing out the ideal groupings of atoms and they conclude it to be characteristic of the liquid state that the smearing-out process increases with the distance of the groupings from the origin atom. The function used for smearing out the

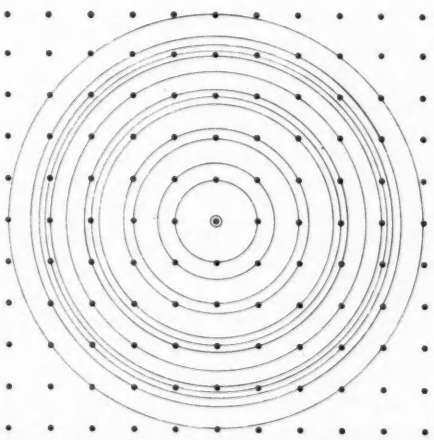

FIG. 1. Square array of atoms in a plane. The large circles are drawn through the atoms of a particular "grouping" or shell.

[1] Prins and Petersen, Physica III, **3**, 147 (1936).

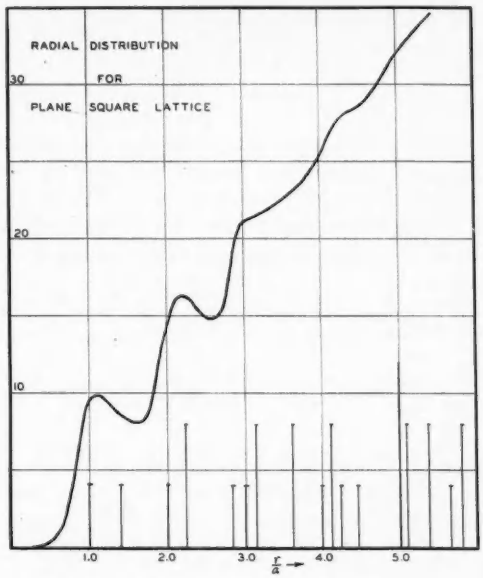

FIG. 2. The ideal distribution of atoms is shown by the vertical lines; the "real" distribution is shown by the smooth curve and it is made up of the sum of the various smeared-out groupings.

various groupings is a Gaussian error curve, and the smeared-out groupings may overlap, even for the nearest ones. The sum of the ordinates of the separate smeared out groupings then gives the resultant distribution curve. That the distant groupings should be smeared out more than the near ones will be clear if it is assumed that the atoms no longer oscillate about fixed points as in the crystal but rather about points which are in motion relative to the origin atom. The expression used by Prins and Petersen is approximately

$$4\pi r^2\rho_k(r) = B_k \exp -b(r-r_k)^2/r_k, \qquad (1)$$

where $4\pi r^2\rho_k(r)dr$ is the probability of finding an atomic center of an atom in the kth shell within a thin spherical shell of thickness dr and radius r; B_k is taken as constant for the kth shell, or grouping, of atoms; b depends on the absolute temperature, r_k is the distance from the origin to the center of the kth grouping; and r is any distance from the origin. On the assumption that the liquid distribution is simply a smeared-out crystalline distribution, each crystalline grouping is smeared out by the expression given in Eq. (1),

and the final distribution is then the sum of all the separate smeared-out groupings. Thus

$$4\pi r^2\rho(r)=4\pi r^2\sum_k\rho_k(r).$$

This smearing-out process has been applied to the ideal distribution, shown in Fig. 2 by the vertical lines, to obtain the "real" distribution shown in the same figure by the continuous curve. The condition has arbitrarily been imposed that the area under each Gaussian curve shall be equal to the number of atoms in the corresponding grouping in the crystal; that is, that

$$\int_{-\infty}^{+\infty}4\pi r^2\rho_k(r)\mathrm{d}r=n_k.$$

Because of the presence of r_k in the exponent of the Gaussian expression, and the consequent broadening of each Gaussian curve as r_k increases, B_k will decrease with increasing r_k in such a way that $n_k=B(\pi r_k/b)^{\frac{1}{2}}$. The choice of b has, of course, been wholly arbitrary, except that the resultant curve should have the general appearance of known distribution curves.

With this illustration of the method of arriving at a distribution curve derived from the crystalline distribution, let us consider the distribution curve for certain actual crystal types. Table I gives the crystalline atomic distributions for simple cubic, face-centered cubic, body-centered cubic, hexagonal close-packed and diamond types of structure.[2] A value for b in Eq. (1) was assumed and various values of B_k were deduced for the various Gaussians in accord with the aforementioned condition. Figure 3 shows the ideal crystalline distributions and the real liquid distributions for body-centered, face-centered and hexagonal close-packed types. Since the choice of b was almost a pure guess, no absolute significance can be attached to these curves, and certain important features may even be masked, for instance, by the choice of too small a value of b. However, this calculation serves to show the general features of the translation from idealized crystal structures to real liquid structures on the basis of the method of Prins and Petersen. The experimentally determined liquid distribution curve for potassium, for which the crystal is body-centered, is shown in Fig. 4 for comparison.[3] Certain similarities are obvious.

The curve in Fig. 4 can be interpreted as follows. Any arbitrary potassium atom has no

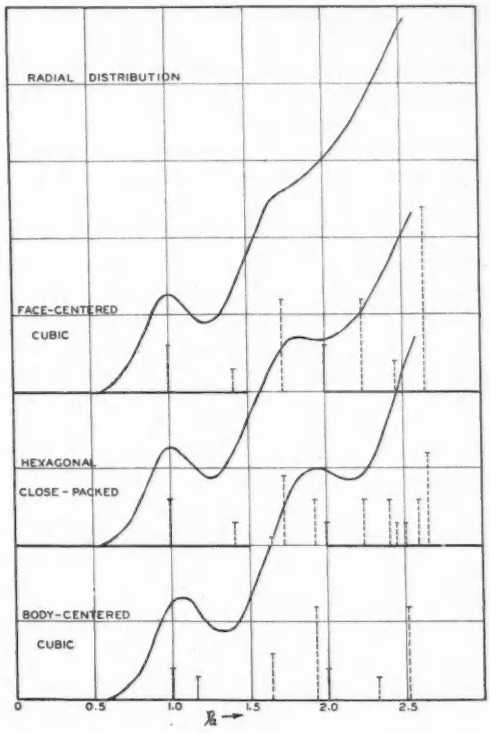

FIG. 3. Smeared-out crystalline distributions for body-centered, face-centered and hexagonal close-packed types of crystal.

TABLE I. *Crystalline atomic distributions.*

k	Simple Cubic m_k	Simple Cubic r_k	Body-Centered Cubic m_k	Body-Centered Cubic r_k	Face-Centered Cubic m_k	Face-Centered Cubic r_k	Hexagonal Close-Packed m_k	Hexagonal Close-Packed r_k	Diamond Structure m_k	Diamond Structure r_k
1	6	1	8	1	12	1	12	1	4	1
2	12	1.41	6	1.16	6	1.41	6	1.41	12	1.64
3	8	1.73	12	1.64	24	1.73	2	1.64	12	1.92
4	6	2.00	24	1.92	12	2.00	18	1.73	6	2.32
5	24	2.24	8	2.00	24	2.24	12	1.92	12	2.52
6	24	2.45	6	2.32	8	2.45	6	2.00	24	2.83
7	12	2.83	24	2.52	48	2.64	12	2.24	16	3.00
8	30	3.00	24	2.58	6	2.83	12	2.45	24	3.27
9	24	3.17	24	2.83	36	3.00	6	2.45	24	3.42
10	24	3.32	32	3.00	24	3.17	6	2.52	24	3.66
11	8	3.47	12	3.28	24	3.32	12	2.59	12	3.79
12	24	3.61	48	3.42	24	3.47	24	2.65	8	4.00
13	48	3.75	30	3.47	72	3.61	6	2.68	24	4.13

[2] Values taken from reference 1.

[3] Thomas and Gingrich, J. Chem. Phys. **6**, 411 (1938).

neighbor nearer than about 3.8A and the mean distance of approach of the nearest atoms is about 4.64A. The origin atom is shielded, to a certain extent, by its nearest neighbors, so that, on the average, the next nearest neighbors do not approach closer than about 9.0A. However, it must be emphasized that, since the distribution curve does not fall to zero between the first and second groupings, the atoms must be continually changing places. At large distances, the prominences are washed out and the distribution, averaged over any usual interval of time, tends toward complete randomicity. The area under this curve between r and $r+dr$ gives the atomic population in this interval. Hence, by planimetering the area under a reconstructed isolated peak, one can estimate the population of any particular grouping.

Hildebrand[4] has reported an attempt to reproduce these distribution curves by what is essentially a mechanical model of highly agitated spheres. The resulting curve gave a distribution similar to that given by curves obtained from x-ray diffraction studies.

Attempts have been made to describe the immediate environment of an atom in the liquid in more detail, and in some of these attempts use has been made of the atomic distribution curves. Wall[5] has assumed that each atom is free to move about in a restricted volume, called the *free volume*, and that this volume is delimited by an abrupt potential wall. On this somewhat simplified assumption, the atomic distribution curves can be used to determine the free volume per atom. The latter is found from these experimentally determined curves to increase with temperature, as would be expected. From well-known thermodynamic relations, heats of fusion and of vaporization have been deduced from the distribution curves, and the calculated values

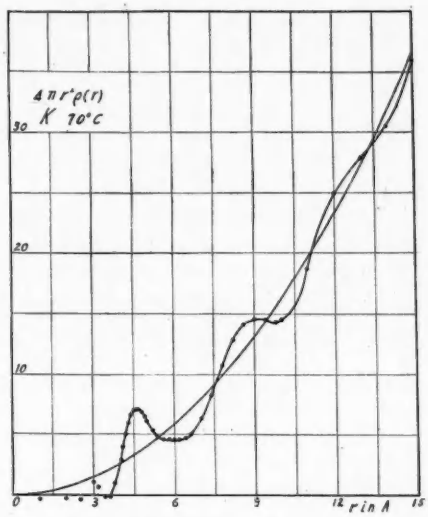

FIG. 4. The experimentally determined atomic distribution curve for liquid potassium. Crystalline potassium is of the body-centered type.

obtained on the basis of this simplified picture are in good accord with experimentally determined values.

Thus, it appears that the structure of a liquid can be described best by means of the atomic distribution curves that are used to describe crystals and gases. X-ray diffraction studies have supplied us with detailed descriptions of the three states of matter, and these descriptions can be presented on an essentially equivalent basis. The advantages of describing the liquid state in terms of similar descriptions of the crystalline and gaseous states seem obvious, and common misconceptions regarding the "structure" of a liquid can be avoided. Preliminary theoretical work making use of atomic distribution curves for liquids has had a certain amount of success and the present active interest in this field will undoubtedly enlarge our knowledge of the liquid state.

[4] Hildebrand, Science **80**, 133 (1934).
[5] Wall, Phys. Rev. **54**, 1062 (1938); see also Coulson and Rushbrooke, Phys. Rev. **56**, 1216 (1939).

Forthcoming Dictionary of Philosophy

THE publishers of PHILOSOPHIC ABSTRACTS, 15 East 40th Street, New York City, have announced for Summer, 1941, publication a one-volume *Dictionary of Philosophy*, edited by Dagobert D. Runes with the collaboration of more than 25 scholars in the field. It will cover metaphysics, epistemology, logic, esthetics, ethics, social philosophy, and the philosophies of education, law and psychology. Special emphasis will be placed on the definition of basic concepts and terms germane to logical positivism, dialectical materialism, mathematical logic, neo-scholasticism, philosophy of science, Chinese, Jewish and Indian philosophy.

A Laboratory Course in X-Rays

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THE laboratory course in x-rays as now given in the Physics Department of this university accompanies a lecture course that meets three hours per week for one quarter, and students are not allowed to take the laboratory work without the related lectures. The two courses are regarded as intermediate in grade, which means that the minimum of acceptable preparation comprises a general course in college physics and a year of calculus. It would be desirable to precede the x-ray courses by courses in physical optics and electrical measurements, but only a minority of those enrolled have had this preparation.

While the courses are designed for students who intend to major in physics and, in some cases, to do research in x-rays, the enrolment also includes a sprinkling of chemistry, engineering and biology majors and the rare premedical student who can offer the prerequisite mathematics.

The experiments to be described are by no means all original, though borrowed material has undergone adaptation to the resources of our equipment, the aptitude of our students and the temperament of our instructors. The necessity for such adaptations has made it impossible to adopt any existing laboratory manual, though books in print[1] contain descriptions of a number of well-designed experiments of suitable grade. Since almost any imaginable x-ray experiment requires several hundred dollars worth of equipment, we have not attempted to provide facilities for simultaneous performance of any experiment by more than one group but have divided the class into small sections which meet at different hours.

The principal source of power for operation of the x-ray tubes is a transformer-rectifier set located in a space adjacent to the laboratory proper. It is screened so as to offer high voltage protection yet is available to students for analysis of the circuits. The 140-kv-peak transformer, the four kenotrons, the banks of Leyden jars and the filter inductances are well separated and so disposed that the layout of circuit elements resembles the conventional wiring diagram. Connections are exposed for the attachment of testing instruments. The primary source of power is a 500-cycle/sec generator remotely located but controlled from the laboratory.

The rectified and filtered output of this plant is conducted by overhead conduits to a lead-walled room within the x-ray laboratory. The room contains two x-ray tube supports mounted on tracks so that a horizontal adjustment of the position of the focal spot can be made by manipulating a calibrated screw outside the room. The tube supports are also capable of adjustment in elevation and in measured rotation about vertical axes. An insulated circulatory system for cooling water is installed in the room. All water-cooled tubes are permanently equipped with short lengths of hose terminating in modified garden hose couplings. Tubes are readily changed without the use of tools.

Outside the lead-walled room and opposite the tubes are two concrete piers which carry the experimental materials or instruments. Permanently mounted on one of these piers is a Bragg spectrometer of conventional general design but equipped with the convenient Nicholas[2] crystal movement which permits direct reading of wavelengths rather than angles. The position of the ionization chamber is not denoted by an angular scale; since the desired displacement of the chamber is always twice that of the crystal, the two have been optically geared together by placing a fiducial mark on the front of the chamber, a mirror on the crystal table and a telescope in a stationary position such that the chamber mark may be seen with the telescope and mirror when the chamber is centered on the reflected beam. If this condition is satisfied for any one crystal position, it suffices for all, since after any crystal relocation the only require-

[1] Especially J. B. Hoag, *Electron and nuclear physics*, ed. 2 (Van Nostrand, 1938) and G. P. Harnwell and J. J. Livingood, *Experimental atomic physics* (McGraw-Hill, 1932).

[2] J. Opt. Soc. Am. and Rev. Sci. Inst. **14**, 61 (1927).

ment is that the chamber be moved until the image of the mark appears at the cross-hair. Crystal and chamber resettings may be made in the few seconds which must be allowed for the electrometer to come to rest after a previous reading. This rapidity of adjustment is important in some of the experiments to be described. In the aperture where x-rays pass through the lead wall to the spectrometer there is a shutter operated by electromagnets under control by the spectrometer operator, who may manipulate the switches directly or attach them to a timing device which may be set to provide any predetermined exposure.

A control desk for the high voltage power plant and the x-ray tube filament circuits is so located at one corner of the laboratory that it is possible for the spectrometer operator to regulate his tube voltage and current, the former by an electrostatic voltmeter and Variac control of the input to the high voltage transformer, and the latter by rheostat adjustments of the storage-battery current supplied to the tube filament. As a rule, however, during class experiments a member of the party handles these controls as his principal duty.

A completely separate and less elaborate high voltage power plant furnishes potentials up to 40 kv for crystal analysis and other experiments which do not require extreme stability or precise input measurement.

Power Plant Analysis

The student makes his acquaintance with the laboratory in an experiment in which x-rays as such play no part. The high voltage equipment which he is subsequently to use rather freely is studied under the guidance of a laboratory instructor, and its electric characteristics are determined. The filter inductances are measured at 500 cycle/sec by the use of ammeter, voltmeter and ohmmeter. The capacitances of the condensers are calculated from the number and dimensions of the Leyden jars, and the residual a.c. ripple accompanying the high potential d.c. output is calculated for various power loads. An RCA oscilloscope is then capacitatively coupled to the high voltage lines through the medium of a porcelain strain insulator as condenser, and the ripples are observed and measured. The high potential voltmeter, which is to be used regularly throughout the course, is calibrated by reference to a wire-wound resistor of approximately 6 megohms resistance.

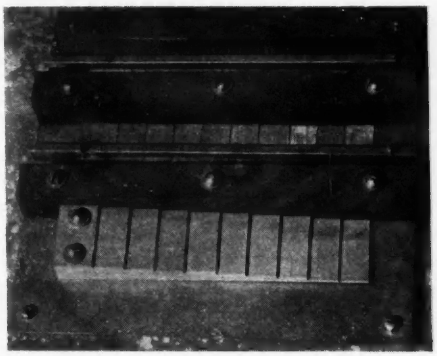

Fig. 1. Step filter with aluminum, copper, iron and carbon absorbers.

Photographic Study of Absorption and Wave-Length

This experiment, suggested by Hoag,[3] conveys important qualitative ideas about the relation of x-ray absorption to wave-length and absorber atomic number and introduces the student to simple photographic manipulations. The compound absorber of Fig. 1 is basically a copper plate 0.06 cm thick upon which systematically varied thicknesses of aluminum, iron and copper are disposed and also, in proximity to the metals, two carbon bars of rectangular section 1.3 cm in thickness.

A radiograph of this object has the appearance of Fig. 2, where it will be seen that the blackening behind the carbon bars is approximately matched by areas which may be found in the series of exposures corresponding to the steps of the metal absorbers. The student is asked to ascertain the thickness of each metal required to match the absorptivity of the carbon for the radiation employed. Since absorptivity (specifically, the product of linear absorption coefficient and thickness) is a variable whose wave-length-dependence for the metals is quite different from that for carbon, it follows that the thickness of metal found to give equivalent absorption is itself a function of wave-length. This ancient

[3] J. B. Hoag, reference 1, p. 214.

principle, once used to compare and specify the hardness of x-radiations, is, in the light of present known absorption coefficients, capable of application as a rough method of wave-length measurement.

From tabulated absorption coefficients, the student prepares a curve showing the relation between wave-length and the ratio of the linear absorption coefficient of a metal to that of carbon. For any particular incident wave-length, this ratio is the reciprocal of the ratio of the matching thicknesses, so a determination of the latter allows the effective wave-length to be read from the curve. Since it usually happens that the metal thickness sought falls between the thicknesses of two adjacent steps of the filter, a method of interpolation is necessary. In view of the limited precision of the whole experiment, a good guess almost suffices; but we have found student guesses something less than good and have, therefore, made use of a simple densitometer consisting principally of an automobile lamp bulb, a photronic cell and a galvanometer. The linearity and calibration of this combination are of no importance since one uses it only for the comparison of a few slightly differing densities and for graphical interpolation in such a series.

It has been the practice to use the total radiation from a tungsten-target tube, filtered only by the copper plate carrying the filters. "Effective wave-length" as determined in this experiment corresponds approximately to the known maximum of the tungsten wave-length intensity distribution. It therefore responds to changes in tube voltage and is independent of tube current, as required exposures bring out. Exposures with tube current and time varied so as to keep a constant product give equal densities, in substantiation of the law of photographic reciprocity.

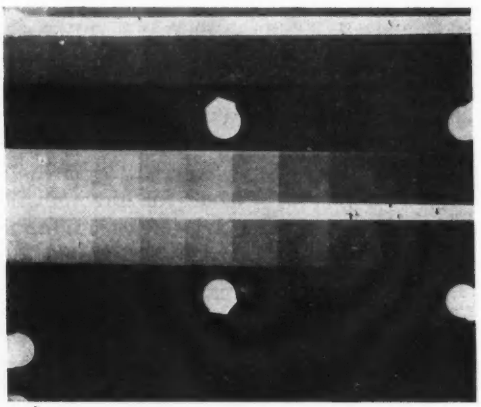

FIG. 2. Radiograph (negative) of the filter of Fig. 1.

CHARACTERISTIC RADIATIONS OF THE ELEMENTS

With the Bragg spectrometer and an all-purpose medical tube used as source, the stronger characteristic lines of tungsten in both the K and L series may be observed in the time allowed by a normal laboratory period. Among commercially available tubes one finds no target element other than tungsten furnishing two accessible series. Molybdenum tubes are standard and are used for a closer investigation of the relative intensities and wave-lengths of the lines of a K series.

The variation with atomic number of the wave-lengths of the principal K-series lines is an important matter which cannot be observed in emission lines without elaborate equipment. We find it convenient to observe the $K\alpha$ lines of many elements by using fluorescent sources and have constructed an experiment that yields a well-filled-out Moseley curve in two hours. A water-cooled tube of small diameter is mounted before the Bragg spectrometer but off the line of the slits so that a specimen of the element to be investigated may irradiate the spectrometer from its position within 2 or 3 in. of the target. A Philips Metallix tube with a tungsten target and a molybdenum-target tube of local origin[4] have been used here with equally good results.

As fluorescers, sheets of zinc, molybdenum, cadmium, tin, tungsten and gold have been used. Substances not available in sheet form, such as arsenic, barium, neodymium and strontium, have been formed into small plaques or packets. With a tube input of 1 kw the intensity of the fluorescence radiation in all these and other cases is such that the $K\alpha$ lines may be plotted by taking half a dozen points each requiring an exposure of about 15 sec. The students are not asked to search for these lines but only to confirm their locations after reference to tables of wave-lengths. About a

[4] This tube and several others used in this laboratory were made to our specifications by James F. Lee, Willow Road, Palo Alto, Calif.

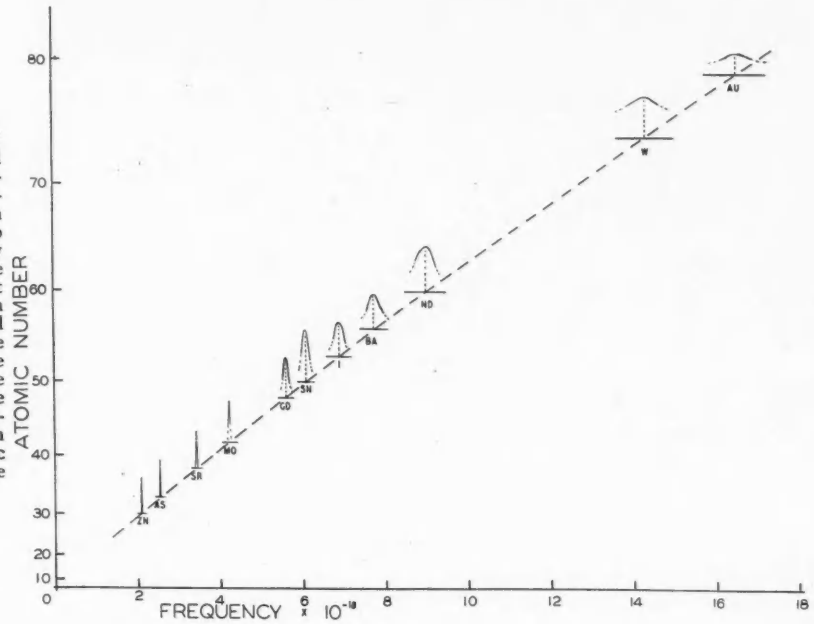

FIG. 3. $K\alpha$ lines of several elements, produced by fluorescence and observed with a Bragg spectrometer. Each spectrum line has been plotted to its own arbitrary intensity scale and on its own base line, located vertically at an appropriate height in relation to the squared atomic number scale. The great variation in line width results from the use of the frequency scale for the horizontal variable. On a wave-length scale the higher atomic number lines would be the narrower.

dozen elements may be observed in a laboratory period. Figure 3 shows typical data displayed so as to show both the relation of frequency to atomic number and the observed line shapes. The student fits an empirical equation to his data and deduces therefrom a value of the Rydberg constant correct to about 1 percent.

DETERMINATION OF h/e

According to the equation of Duane and Hunt, the energy Ve of an accelerated electron is equal to the maximum quantum energy $h\nu$ that may be emitted in a collision which brings the electron to rest. Evidently observations of V and ν suffice to determine the ratio h/e. The intensity in the continuous x-ray spectrum from a thick target falls off to zero as the limit frequency is approached; so ν can be ascertained only by extrapolation to zero of a curve of spectral intensity *versus* x-ray tube potential, for some constant ν, or of spectral intensity *versus* frequency, for constant V.

Both procedures are used in this experiment. Since an intense continuous spectrum is an advantage, a tungsten-target tube is used. Observations are performed with the Bragg spectrometer after a check on the calibration of its wave-length scale, performed by observing the position of the strong alpha-lines from a molybdenum tube. In order to be entirely independent of spectrometer scales, the crystal is sometimes adjusted to reflect the peak of the calibration line and left in this position for observations on the same wave-length, as found in the continuous spectrum from the tungsten target. In this case the tabular wave-length value gives ν, and a series of values of the reflected intensity for successive tube voltages over a range of 200 or 300 v in the neighborhood of the voltage at which the intensity vanishes gives the critical voltage V. Two curves of each type, yielding four separate determinations of h/e, can be obtained in the allotted period by an average laboratory party. The separate values may be expected to agree with one another and with the supposedly correct value to within 0.5 percent. Figure 4 shows sample data.

ABSORPTION COEFFICIENTS AND LAWS

Since the most famous property of x-rays, popularly speaking, is concerned with absorption characteristics, and since these characteristics

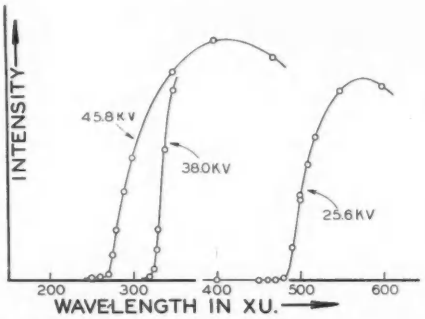

FIG. 4. Short-wave portions of continuous x-ray spectra produced by three different potentials.

illuminate several comprehensible theoretical points, it is considered desirable to bring out in student experiments (a) the existence and nature of absorption discontinuities or limits, (b) the wave-length variation of the absorption by a given substance in the wave-length regions between the limits, (c) the variation of absorption (specifically, mass absorption coefficient) at a given wave-length with atomic number of the absorbing substance. These are mainly quantitative matters; and while the existence and wave-length positions of limits may be shown photographically, the measurement of coefficients calls for the Bragg spectrometer.

For quick observation of a K-limit, we use a 1-kw tungsten tube before the spectrometer and observe the continuous spectrum in the neighborhood of the silver limit wave-length, taking observations separated about 5 X units on the wave-length scale. At each wave-length setting one observation is made with a 0.05-mm sheet of silver interposed in the beam at some point and one observation is made with the silver removed. Each pair of observations yields a value of μx from which the linear absorption coefficient μ might be obtained with the use of a micrometer measurement of x, the thickness of the absorber. However, an ordinary micrometer measurement of this small thickness would not be sufficiently precise to accompany the intensity measurements; moreover, the linear absorption coefficient is of less interest than the mass absorption coefficient, that is, the ratio of μ to the density ρ of the absorber. But

$$\mu/\rho = \mu x/\sigma,$$

where σ is the *surface density* of the absorber, a quantity that may be evaluated from the measured mass and area of the absorber. The mass-absorption coefficient μ/ρ thus obtained is the quantity plotted as a function of wave-length.

Observations of L-absorption limits may be made most conveniently by using an absorber consisting of a small quantity of finely powdered uranium dioxide folded in filter paper or between strips of Scotch tape. The thinnest layer which appears continuous will suffice. Mass-absorption coefficients cannot be accurately obtained with such an absorber because of the probable discontinuousness of the area presented to the radiation, but the three L-absorption jumps may be plotted as in Fig. 5.

For comparing the mass-absorption coefficients of various elements at a single wave-length, it would be convenient to use as source a target with $K\alpha$ lines at about 0.35A, but such x-ray tubes are not available if even practicable. We have found it satisfactory to isolate such a wave-length with the Bragg spectrometer from the continuous spectrum of a tungsten target rather than to use a line radiation from such a source as a standard molybdenum tube which, though readily accessible, has the disadvantage of being too soft for use with conveniently obtainable sheets of the heavier metals.

Mass-absorption coefficient determination by the method just described requires absorbers in the form of sheets or blocks, uniform in thickness and with geometrically simple outlines (squares, rectangles) which permit the areas to be determined easily. About 20 such specimens, ranging from aluminum to lead, furnish a good curve of mass-absorption coefficient *versus* wave-length through a region containing a K discontinuity.

CRYSTAL ANALYSIS

The laboratory is equipped with a variety of Laue cameras, apparatus for powder diffraction and for rotation and oscillation photographs. Most of this equipment is of local construction but the methods of use are approximately the standardized ones. Though the equipment is adequate for structure research the laboratory exercises are, as a rule, confined to verification of

the structures of simple inorganic crystals. A complete Laue spot analysis of a cubic crystal (NaCl or KCl) is performed in which the student is asked to account for every spot recorded, stating the indices of the reflecting planes, the planar spacings, the wave-lengths reflected and the orders of reflection. Simple powder diffraction patterns are obtained and these are interpreted with the aid of Hull-Davey semilogarithmic charts, mounted photostatic enlargements of the published charts being provided for this purpose.

Refraction and Total Reflection

The most important application of total reflection of x-rays is found in the diffraction grating, but the phenomenon is of sufficient theoretical interest to justify inclusion here apart from applications. A series of reflectors including bismuth, gold, platinum, lead, silver, palladium and aluminum was prepared by condensation of the metals in vacuum upon pieces of plate glass which had been selected for planeness. A tilting table, powered by a small, slow-speed synchronous motor and driving cam is mounted on a stand about 2 m from the powder diffraction apparatus. The tube in this apparatus has a molybdenum target whose face, disposed horizontally above the filament, presents a virtual line source as seen from the tilting table. A horizontal slit mounted outside one of the ports of the diffraction apparatus limits the radiation proceeding toward the tilting table to a narrow and nearly horizontal ribbon whose vertical thickness and downward inclination can be controlled by means of adjusting-screws at the slit.

This ribbon of radiation impinges upon the metal reflecting surfaces, one or more of which lie on the tilting table. The table is adjusted to oscillate through a range which will cause the angle of incidence to pass through the critical values, the totally reflected beams being received upon a photographic film 2 m farther along. In such a photographic record a discontinuity in blackening appears where the reflected-beam intensity goes abruptly to zero at the critical angle. The measured positions of these discontinuities lead to critical-angle values and to values of the refractive indices that check within 5 or 10 percent with those to be expected from theoretical dispersion equations. The discrepancy is largely because of the lack of sharpness of the critical angle which absorption causes, combined with the fact that the apparent position of an unsharp edge depends upon the exposure. While the absorption effect impairs the precision of the experiment, it is itself of significance and interest, and deserves attention.

Grating Wave-Lengths: the Avogadro Number

The logical introduction to the measurement of x-ray wave-lengths is by the use of the artificially ruled diffraction grating since, in this case, the grating space is subject to direct measurement. Measurement of the wave-length of a single characteristic line by means of the grating and then by crystal reflection serves to calibrate the crystal, which can thereafter be used with a confidence not logically possible when reliance is placed solely upon book values of crystal constants.

We have prepared diffraction gratings by condensing heavy metals upon optically flat glass and scribing with a hardened steel tool through the metal layer to the glass backing. Aluminum has been generally used for the production of optical diffraction gratings in this way; but in the case of x-rays a large grazing critical angle is desirable, which calls for a higher electron density than is possessed by aluminum. Gold is readily applied by the condensation method but it does not adhere well to glass, since it comes up in strips and flakes under the ruling tool. However, a satisfactory coating is obtained by first aluminizing lightly and following with an

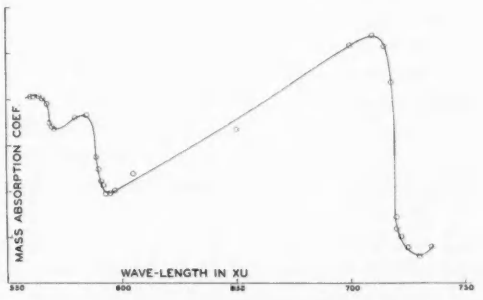

Fig. 5. *L*-absorption discontinuities of uranium.

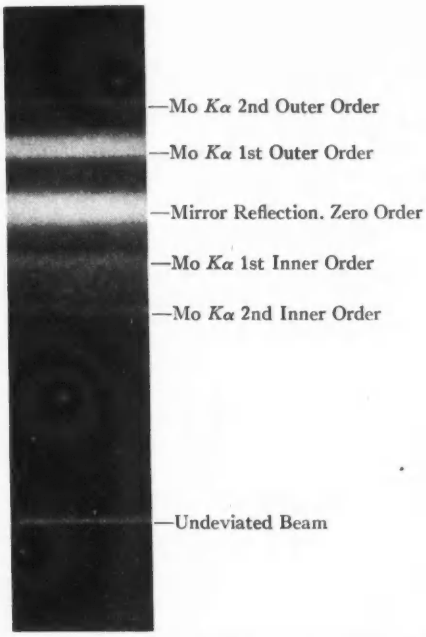
—Mo Kα 2nd Outer Order
—Mo Kα 1st Outer Order
—Mirror Reflection. Zero Order
—Mo Kα 1st Inner Order
—Mo Kα 2nd Inner Order
—Undeviated Beam

FIG. 6. Molybdenum K spectrum observed with a ruled grating.

opaque gold top coat; the gold adheres well to the aluminum and the combination rules well.

Since x-ray gratings can be used only with a small grazing angle of incidence, a relatively large spacing is required, notwithstanding the shortness of x-ray waves. For observation of the molybdenum K lines, 500 lines/cm is appropriate and it was found possible to rule such gratings on a small ruling machine designed for engraving scales. The resulting gratings have not, so far, been sufficiently uniform for research purposes but permit measurement of the wave-length λ of the strong molybdenum doublet with an error of less than 1 percent. Figure 6 shows four measurable orders of the unresolved α-lines, the β-lines being suppressed with a zirconium filter. A simple spectrograph with a rocksalt crystal may now be mounted before the same source and the Bragg angle θ for these same lines measured in the first order from a 5-min exposure.

This comparison not only calibrates rocksalt as a means of wave-length measurement but furnishes the principal data for a determination of the Avogadro number. Elementary textbooks show that the principal grating space of rocksalt is given theoretically by the formula

$$d=[M/2N\rho]^{\frac{1}{3}},$$

in which M and ρ are the molecular weight and density, respectively, of NaCl, and N is the Avogadro number. Combining this with Bragg's law, we have

$$N=4M\sin^3\theta/\rho\lambda^3,$$

from which N can be computed upon observing any wave-length λ in the first order.

COMPTON EFFECT

The stands for supporting x-ray tubes have been mentioned. Ordinarily the target of the tube is placed on the vertical axis of rotation; when one is observing the Compton shift this position is occupied by the scattering body, and the molybdenum-target, water-cooled tube is mounted with its own axis vertical and situated less than 3 in. from the scatterer. This proximity is necessary in order to obtain intense scattered radiation, and it is possible because of the slender design of the tube. As scatterer a $\frac{3}{8}$-in. arc carbon, vertically mounted, is satisfactory. This whole assembly is positioned horizontally so that the Bragg spectrometer receives radiation from only the scatterer. The angle of scattering may be varied as desired by rotating the stand on its vertical bearings, an operation that does not displace the scatterer but swings the tube around it.

The spectrometer slits are opened until the

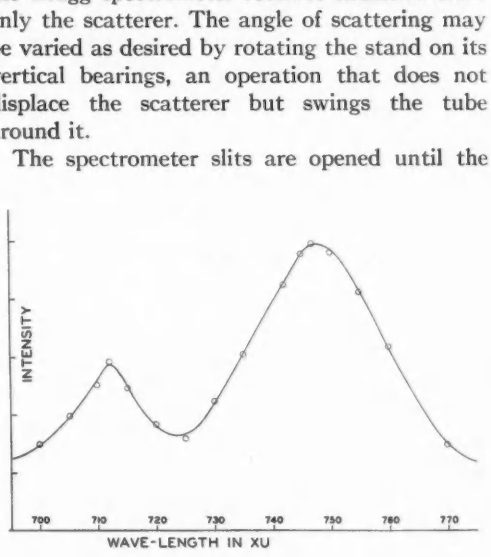

FIG. 7. Spectrum of scattered molybdenum $K\alpha$ radiation showing unmodified (left) and modified lines.

inhomogeneity of the Bragg angle is about 20′. A series of spectrometer observations in the neighborhood of the Mo $K\alpha$ lines is conducted, using exposure times of 20 sec and getting electrometer deflections of about 10 mm at the tops of the lines. The curve of Fig. 7 was obtained by a student group in half an hour. Two or three such curves taken at different scattering angles may be obtained in a laboratory period. Collectively they show a dependence of the shift upon scattering angle, which is in accordance with the Compton formula, and each curve contains the data necessary for a separate determination of the ratio h/mc.

An Experiment for the Determination of Work Function Through Calorimetric Measurements

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IN view of the general use of thermionic currents in vacuum tubes, it is natural that laboratory work in physics should include fundamental experiments on thermionic emission of electrons. A popular experiment is the determination of emission as a function of cathode temperature. This gives information of direct value in applications, because the most practical question concerns the amount of the emission at any temperature. The experiment may be performed with comparative ease if the required accuracy is not too great. Furthermore, the variation of the current as a function of the temperature may be analyzed in the well-known Richardson[1] plot to give the work function. However, the theory[2] underlying such analysis makes this experiment for determining the work function most suitable for advanced students. The present paper emphasizes the simplicity of the concepts underlying the determination of work function by the calorimetric method and suggests an experimental arrangement that may be used either to demonstrate the cooling effect of electron emission before a class or to facilitate a direct measurement of work function in the laboratory.

Thermionic emission is an evaporation process. There is a general analogy between the loss of electrons from a metal and the loss of molecules from a liquid surface. In either case the asymmetry existing at the surface gives rise to forces retarding the escape of the emerging particles, and the only ones to escape are those that come to the surface with components of momentum perpendicular to the surface considerably above average. Thus it is the particles of highest energy that have the greatest chance to escape. Consequently, two of the chief facts of experience may be explained. The first of these is that the number of particles having momentums permitting their escape from the surface increases rapidly as the average energy of the particles (and hence the temperature) is increased. In the one case this corresponds to the rapid increase of vapor pressure with temperature. In the other case it corresponds to the rapid increase in thermionic emission with temperature. The second fact is that cooling accompanies the evaporation. Since the proportion of escaping particles is largest for the particles of highest energy, the average energy of those remaining would naturally be reduced, and, unless additional energy is supplied, the temperature falls. This accounts for the heat of vaporization.

In the case of a liquid, the heat of vaporization is most frequently measured directly in a calorimetric experiment. The Clapeyron-Clausius equation, however, provides information relating the heat of vaporization to the rate of increase of vapor pressure with temperature. For practical reasons it is sometimes preferable to determine the heat of vaporization from the vapor pressure curve, just as the work function of a metal is most frequently determined from a Richardson plot.

The thermionic work function corresponds to the amount of energy that must be given to a free electron to permit its escape against the surface forces. The work function which is

[1] O. W. Richardson, Phil. Mag. **28**, 633 (1914).
[2] S. Dushman, Phys. Rev. **21**, 623 (1923).

determined in a calorimetric experiment measures the average difference of energy between the escaping electrons and those supplied to the filament from the plate return-circuit. This quantity, though not identical with the work function obtained from a Richardson plot, does not differ much from it. Thus the heat of vaporization of electrons provides a direct means for measuring work function, and the physical concept underlying the method is very simple and definite. Cooke and Richardson[3] and also Davisson and Germer,[4] by means of delicate calorimetric experiments, have thus determined work functions. The bridge method for accomplishing such measurements, which is described in this paper, most closely resembles the experiments of Richardson, and it is simple enough to be used either for demonstrating the cooling effect before a class or for the measurement of various work functions in a laboratory experiment.

An experiment on the cooling effect will naturally resemble work with a continuous flow calorimeter. It is not convenient, however, to eliminate radiation from the cathode system; so that, in place of considering the total power input, we measure small changes produced by electron evaporation and deduce the required information from these. For the demonstration of the effect, it would be sufficient to connect the filament of a diode under test as one arm of a resistance bridge, and to observe the unbalancing of the bridge when the plate circuit is closed. It would be possible, of course, from a determination of the temperature change and certain other data, to deduce the energy carried away by the electrons. This, however, is not the most direct procedure. The idea underlying the experiment discussed here is to maintain the temperature of the filament constant, regardless of whether or not it is emitting electrons, by supplying and measuring the change in power required to maintain the temperature. Since the filament under test is used as one arm of a resistance bridge, balancing the bridge with definite values of the auxiliary resistances requires a fixed filament resistance and, hence, a definite temperature. If the bridge is balanced first without emission of electrons and then with emission, the increment of the power supplied to the filament just equals the power removed through the evaporation of electrons. The theory of the experiment is easily developed on this basis.

If we let φ stand for the thermionic work function as expressed in volts and i for the thermionic emission in amperes, the power in watts removed from the filament through the evaporation of electrons is the product of these factors; that is,

$$\Delta P = i\varphi. \tag{1}$$

If we let V_0 stand for the potential difference across the filament and I_0 stand for the heating current when emission is not allowed, values of $V_0+\Delta V$ and $I_0+\Delta I$ will be required to maintain the temperature when emission is permitted. The increment ΔP of the supplied power is $I_0\Delta V + V_0\Delta I + \Delta V\Delta I$. Since the product $\Delta V\Delta I$ is very small compared with the other terms, it may be neglected. Hence we may write

$$\Delta P = I_0 V_0\left(\frac{\Delta V}{V_0}+\frac{\Delta I}{I_0}\right).$$

Since the resistance is maintained constant, $\Delta V/V_0 = \Delta I/I_0$, and

$$\Delta P = I_0 V_0(2\Delta V/V_0). \tag{2}$$

When this increment of power is equated to that removed from the filament by the evaporation of electrons and the resulting expression is solved for the work function, we have

$$\varphi = I_0 \cdot 2\Delta V/i. \tag{3}$$

A circuit developed to facilitate work function measurements by this method is shown in Fig. 1. It is basically a resistance bridge, having equal resistances of 500 ohms for each of the ratio arms and having the filament under test in the upper right-hand arm. An essential feature of this special bridge is the arrangement whereby the plate current, or a definite fraction of it, is returned to the midpoint of the comparison resistor R, so that no spurious currents through the galvanometer result from the plate current itself. The resistors used in all arms, except that containing the filament, have negligible temperature coefficients of resistance, so that they re-

[3] Cooke and Richardson, Phil. Mag. **25**, 624 (1913); **26**, 472 (1913).
[4] Davisson and Germer, Phys. Rev. **20**, 300 (1922); **24**, 666 (1924).

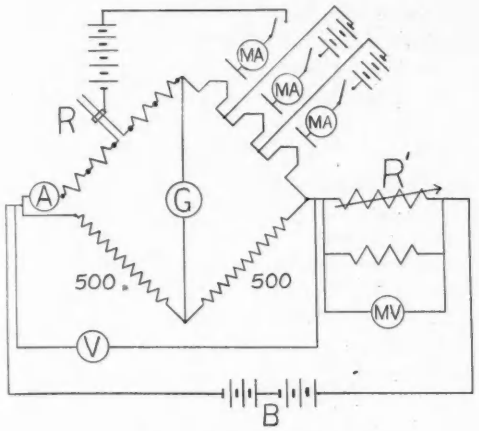

FIG. 1. Diagram of circuit.

main constant regardless of the potential difference across the bridge. The balance of the bridge as indicated by the galvanometer G is very sensitive to changes of filament temperature. In operation, the bridge is first balanced at a suitable filament temperature with the plate circuits open. The plate circuits are then closed, permitting the emission of electrons, thus cooling the filament and unbalancing the bridge. The balance is then restored by slightly increasing the power supplied through decreasing the resistance R', a carbon compression rheostat in parallel with a shunt. Since the bridge is supplied by a constant source of electromotive force B, the change in the reading of the millivoltmeter MV may be taken as the change in the total potential difference across the bridge. This is just the quantity $2\Delta V$ which, together with the ammeter reading and the sum of the milliammeter readings, is needed for substitution into Eq. (3) for the computation of the work function.

Details concerning the construction and operation of the bridge may be of interest to some readers. For the galvanometer, a simple null indicating instrument of moderate sensitivity will suffice. Our galvanometer had a resistance of 100 ohms and a voltage sensitivity of 0.3μV/mm. Even the small thermionic currents used in these tests caused galvanometer deflections of 500 to 1000 mm. Hence reasonable accuracy would be obtainable with a galvanometer only one-tenth as sensitive.

Since the changes to be detected are relatively small, care must be exercised in constructing and assembling the apparatus. The comparison resistor R, shown as the upper left-hand arm of the bridge, must have a negligible temperature coefficient of resistance and must be capable of carrying the full filament current of the tubes used without excessive heating. If the filaments used in the upper right-hand arm are connected by means of regular tube bases, the contact resistance between bases and sockets in the filament circuit may vary and give trouble. This can be corrected by soldering flat strips of sheet metal to the filament prongs of the base in such a way that they protrude between the socket and the base to provide convenient lugs for making soldered connections in the filament circuit.

The comparison resistor R is assembled of accurately matched coils which are used in pairs together with a double slide wire as shown, in such a manner that a plate return-connection may be made to the exact middle of R. This is done so that the average currents in the two upper arms of the bridge may be identical regardless of the plate current. This device for the elimination of spurious currents through the galvanometer may be used with any number of filament sections including a simple undivided filament. It is desirable, however, that the current through the various parts of the filament should be very nearly constant. For this reason the filament is constructed in short similar sections (in practice, separate vacuum tubes with similar cathodes) to which the plate currents may be returned separately.

Conditions are adjusted so that the bridge is balanced when the right- and left-hand arms have the same resistance, regardless of the plate current i. The part of the plate current in each section can be adjusted by variation of the separate plate potentials so that it becomes exactly i/n, where n is the number of sections. Hence, if the bridge current indicated by the ammeter is I_0, the potential drop between the ammeter and the midpoint of the arm will be $\frac{1}{2}I_0R$, while that between the midpoint and the galvanometer connection will be $\frac{1}{2}(I_0+i/n)R$. Hence the total drop of potential across the arm is $R(I_0+i/2n)$. In each section of the filament, the incoming electron current is I_0+i/n, while the outgoing filament current is reduced to I_0 by the electron emission from the section. Hence, if the emission is symmetrical about the midpoint of the resistance for the section, the potential drop in each section is $(I_0+i/2n)R/n$, and in the n sections we have a total drop of $R(I_0+i/2n)$, which shows that the bridge is balanced for equal resistances, regardless of the plate current.

For determining the work function of tungsten, special experimental tubes were constructed having simple filaments of the hairpin type. The General Electric FP-400 was also found to be satisfactory when used in series by pairs, so that the springs keeping the filament taut could be arranged symmetrically about the midpoint of the arm. The reliability of the results may be increased by averaging observations for the two directions of the bridge current. For determining the work function of the oxide-coated cathodes in commercial radio tubes, the

TABLE I. *Representative measurements.*

TUBE	FILAMENT TYPE	NUMBER n OF TUBES	I_0 (AMP)	i (AMP)	$2V_0$ (VOLT)	$2\Delta V$ (VOLT)	φ (VOLT)
Special	Tungsten	3	2.72	0.0132	22	0.0214	4.4
FP-400	Tungsten	2	2.10	.0147	14	.032	4.57
46	Oxide-coated	2	1.57	.048	8	.048	1.57

use of type 46 and 47 tubes was found convenient, because the electric characteristics of these filaments did not differ too much from those of the tungsten filaments to permit the use of the same comparison coils in the tests.

Representative measurements are shown in Table I. These results are quite satisfactory. For both tungsten and oxide-coated cathodes they indicate the magnitude of the work function reliably.

Although in these experiments the power changes involved were quite small (in no case greater than a few percent of the total power and usually only a few tenths of a percent), the circuit described permitted reliable measurements to be made without great difficulty, using only the instruments ordinarily available in the laboratory. The order of magnitude of the input power was easily estimated from the ammeter and voltmeter readings with a likely error of less than 1 percent. The change in the potential difference across the bridge was measured on an accurate millivoltmeter with a likely error of not more than 2 percent of the difference. Thus, the simplicity both of the ideas involved and of the methods used contributes to bringing calorimetric measurements of work function within the range of the undergraduate physics laboratory.

On the Training and Prospects of the Ph.D. in Physics*

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THE subject of this paper is a very broad one, and, with sufficient preparatory investigation, one could write a really informing and valuable monograph. I hope that some day this may be done. The present paper is scarcely more than a sort of introduction to such a monograph. In its preparation I have used only such printed material as is readily available to me, and I confine my discussion almost entirely to conditions at the University of California. To be able to write with any authority on conditions at other institutions, one should first visit each institution and, by personal interview and direct inspection, determine the actual training and prospects of its Ph.D. candidates.

The tables that I have compiled[1] for this paper form a partial answer to the questions: "How many students get the Ph.D. degree in physics, where do they get it, and why do they get it where they do?" Table I gives the total number of Ph.D. degrees awarded in physics during the 14-year period 1925–1939, listed by institutions in the order of number of degrees. No data are available for earlier years, except for the single year 1921–22 (N.R.C. Reprint No. 42). Unfortunately even the totals given here are not reliable. In both the N.R.C. Reprints (covering the period 1925 to 1933) and the Wilson pamphlets (covering the period 1933 to 1939), the strange practice has been followed of listing a thesis under the field where, from its title, it *appears* to belong, instead of always under the department in which the work was done! Thus several theses at the University of California are listed under "Physics," when the actual work was done in the Department of Chemistry or Elec-

* An invited paper read at the Seattle meeting of the American Association of Physics Teachers, June, 1940, with minor deletions and revisions.

[1] The chief source material used is as follows:

(A) Reprint and Circular Series of the National Research Council No. 26, 42, 75, 80, 86, 91, 95, 101, 104 and 105, entitled "Doctorates conferred in the sciences by American universities" (to be referred to as "N.R.C. Circulars").

(B) H. W. Wilson Co. pamphlets No. 1 to 6, entitled "Doctoral dissertations accepted by American universities" (to be referred to as "Wilson pamphlets").

(C) U. S. Office of Education, Circulars No. 149, 168, 172, 176 and 183, entitled "Land-grant colleges and universities" (to be referred to as "U. S. Circulars").

(D) American Council on Education "Report of committee on graduate instruction," 1934.

(E) Stephen S. Visher, "Distribution of the younger starred scientists," Am. J. Sci. **237**, 48 (1939). See also Visher, J. Higher Ed. **10**, 117 (1939).

TABLE I. *Number of doctor's degrees in physics, 1925–1939.**

1	DU	128	California Institute (10½)	32	L	13	Purdue
2	DU	112	Chicago (7)	33		13	Washington (Seattle) (1)
3	DU	107	Michigan (5)	34		12	Boston (1)
4	DUL	100	California (7)	35	U	12	Catholic (1)
5	DUL	96	Cornell (6)	36	U	11	North Carolina (2)
6	DUL	71	Wisconsin (3)	37	A	10	Rice
7	DU	66	Johns Hopkins (5)	38	U	9	Kansas
8	DUL	64	Massachusetts Institute (9)	39	U	9	McGill**
9	DU	62	Columbia (5)	40	AU	9	Northwestern
10	DU	60	Yale (6)	41		9	Rensselaer Polytechnic
11	DU	59	Harvard (9)	42		9	St. Louis
12	AUL	56	Illinois (3)	43	UL	7	Missouri (1)
13	A	47	New York	44		5	Colorado
14	DU	47	Princeton (8)	45		4	Carnegie Institute (1)
15	AUL	43	Ohio State (3)	46	U	4	Clark (1)
16	U	42	Indiana	47		3	American
17	AUL	40	Minnesota (2)	48		3	Lawrence (Appleton)
18	AU	39	Iowa (1)	49		3	Radcliffe
19	AU	30	Virginia (1)	50	L	3	Rutgers
20	AU	25	Pennsylvania (1)	51		3	Syracuse
21	U	24	Toronto**	52		2	George Washington (3)
22	L	20	Pennsylvania State	53	L	2	Kentucky
23	A	19	Pittsburgh (1)	54	L	2	Oregon State
24		18	Rochester (1)	55		1	Brooklyn Polytechnic
25	AU	17	Stanford (2)	56		1	Bryn Mawr
26	L	16	Iowa State	57		1	Fordham
27	U	16	Texas	58		1	Marquette
28	AU	16	Washington (St. Louis) (2)	59	UL	1	Nebraska
29		15	Cincinnati (1)	60		1	Oklahoma
30	AU	14	Brown	61		1	Smith
31	U	13	Duke (1)	62		1	Southern California

* D = "distinguished," A = "adequate," L = land-grant institution, U = member of Association of American Universities, ( ) = number of staff members starred in *American Men of Science*.
** 1933–39 only.

trical Engineering. Doubtless there are many similar cases at other institutions. Of course, our department has no objection to research in pure physics being done in the chemistry department —on the contrary, we feel gratified at this implicit recognition of the importance of physics —but we have not suspected that such a practice would result in certain quite loyal chemists being officially listed as physicists!

Table I gives other information about the 62 institutions that have awarded at least one Ph.D. degree in physics during the 14-year period specified. In 1934 the American Council of Education obtained by vote a rating of the various departments of graduate instruction with respect to the adequacy of facilities for work leading to the doctor's degree. In this vote, 12 departments of physics were designated as "distinguished," and these are indicated by "D" in Table I. Thirteen were designated as "Adequate" and are indicated by "A" in Table I. The letter "U" indicates that the institution in question is a member of the Association of American Universities. This association is interested primarily in graduate instruction, and membership in the association is based on the excellence of graduate instruction, integrated over all departments. The letter "L" indicates a land-grant institution.

The numeral in parenthesis after the name of the institution gives the number of persons on its staff starred in physics in *American Men of Science*. Visher[1] lists only those first starred in editions 3 to 6, inclusive. To his list I have added the 13 persons, starred in physics in editions 1

and 2, who were still in active service in January, 1939 (the date of Visher's paper). It should be noted that in the case of the Canadian universities, Toronto and McGill, the figure for the total number of Ph.D. degrees refers to the 6-year period 1933–1939 only.

Table I contains a number of interesting facts. The total number of doctorates conferred in physics in the 14-year period is 1647, distributed over 62 institutions, or an average of 1.9 degrees per institution, per year. The California Institute of Technology, at the top of the list, has conferred an average of 9.14 degrees per year, while 8 institutions have each conferred only one degree during the entire 14 years. The California Institute of Technology also has the largest number of starred physicists (the *half-man*, who is Professor von Kármán, is due to Visher, not to me).

Of the 1647 degrees, 972, or 59.0 percent, were awarded by the 12 "distinguished" departments, and 365, or 22.2 percent, by the 13 "adequate" departments. These 25 departments thus account for 81.2 percent of all the degrees. Moreover, the first 11 places in the table are occupied by "distinguished" departments. Only Princeton University is out of line, and this institution has deliberately kept its enrolment relatively small. In this connection, I quote the only figures I now have for the number of graduate students in physics at various institutions. These apply to the year 1938–39, and are: University of California (Berkeley only), 87; University of Michigan, 78; California Institute of Technology, 48; Princeton University, 22.

Table I also indicates one reason why certain departments were voted as "distinguished." Of the total of 110.5 starred physicists in the table, 80.5, or 72.8 percent, are in the 12 "distinguished" departments (which gave 59 percent of the degrees), and only 16 are in 9 of the 13 "adequate" departments, with the remaining 14 scattered among 11 other institutions. Thirty of the 62 institutions have no starred physicists.

Returning to the number of degrees awarded, we find 310 degrees awarded by 37 different departments, voted in 1934 as not even adequate for doctorate work in physics. Now, it must be admitted that several of these 37 departments, if a vote were taken today, would almost certainly be designated as "adequate." But it should be remembered that the degrees conferred in 1939 or earlier were on students who, in general, entered the institution previous to 1936, and hence the 1934 vote is probably more appropriate than a 1940 vote would be, when used in connection with the total number of degrees granted between 1925 and 1939.

I desire to draw no particular conclusions as to the 310 degrees conferred by 37 institutions. You may draw your own. I am merely presenting the facts. Omitting Indiana, with its 42 degrees, one gets an average of almost exactly 1 degree each 2 years for the 36 institutions in question, compared to 2 degrees per year for the 13 "adequate" departments, and 6 per year for the 12 "distinguished" departments.

Table I has shown the distribution among *institutions* of the doctor's degrees in physics. Table II is designed to show the distribution in *time*, and also to compare physics with all sciences, and with all subjects. Column (2) gives the total number of doctor's degrees in all sciences, conferred during the academic year specified. Column (3) gives the total number of institutions concerned. For the interval 1911 to 1933, inclusive, these figures may be obtained directly from the N.R.C. Circulars. For the 6-year period 1933–1939 the listed figures have been obtained by eliminating all doctor's degrees not in science, and all institutions giving no degree in science, from the figures for all departments (scientific and nonscientific), as listed in the Wilson pamphlets.

Columns (4) and (5) correspond to columns (2) and (3) but refer to physics alone. They were obtained from the same sources. Column (7), giving the number of degrees in physics at California, comes from our own departmental records. Five degrees had been awarded prior to 1911–12.

Some of the results in this table are to me quite unexpected. One may not be surprised at the sixfold increase in the number of physics degrees during the past quarter century, but it may be a surprise to learn that science as a whole has shown precisely the same increase. This is indicated by the remarkable constancy of column (6). The degrees in physics comprise consistently about 10 percent of the total number in science.

TABLE II. *Number of doctor's degrees, and number of institutions awarding them.**

(1) Year	(2) All Science	(3) Number of Inst.	(4) Physics	(5) Number of Inst.	(6) % of (2)	(7) Physics, Calif.	(8) All Subjects	(9) Science % of (8)
38–39	1651	74	165	48	9.99	8	2928	56.38
37–38	1522	75	148	44	9.72	14	2768	54.98
36–37	1517	75	157	40	10.35	8	2709	55.99
35–36	1547	74	143	40	9.24	1	2683	57.65
34–35	1534	75	149	40	9.71	11	2649	57.90
33–34	1550	74	121	41	7.80	4	2620	59.16
32–33	1343	63	123	33	9.16	8	2462	54.55
31–32	1241	58	113	32	9.11	8	2368	52.41
30–31	1147	63	94	29	8.19	7	2183	52.54
29–30	1074	59	89	25	8.29	7	2078	51.68
28–29	1025	57	101	25	9.85	8	1912	53.61
27–28	842	52	79	26	9.38	2	1548	54.39
26–27	796	53	90	25	11.31	6	1504	52.93
25–26	748	51	75	26	10.03	8		
24–25	640	41	59		9.22	2		
23–24	611	42	58		9.49	1		
22–23	575	38	54		9.39	5		
21–22	454	39	56		12.33	2		
20–21	334	34	28		8.38	1		
19–20	328	36	19		5.79	1		
18–19	180	29	18		10.00	1		
17–18	293	32	17		5.80	2		
16–17	372	33	32		8.60	2		
15–16	332	27	35		10.54	1		
14–15	309	29	31		10.03	2		
13–14	241	28	23		9.54	0		
12–13	234	28	22		9.40	0		
11–12	273	29	30		10.99	0		
Totals	22,713		2129			120		

* Data from N.R.C. Circulars and Wilson pamphlets. N.R.C. Circular No. 26 gives data of col. (2), for 10-year period 1911–1921. Wilson pamphlet No. 3 gives data of col. (8), for 10-year period 1926–1936.

TABLE III. *Land-grant institutions, 1938–39.**

(1)	(2) Graduate Enrolment	(3) Total Master's	(4) Total Doctor's	(5) Ratio (2) to (3)	(6) Ratio (2) to (4)
1. California	3244	456	99	7.11	33.8
2. Cornell	1050	240	130	4.37	8.1
3. Illinois	1502	579	106	2.59	14.2
4. Iowa State	727	159	46	4.57	15.8
5. Kentucky	435	129	7	3.37	62.1
6. Massachusetts Institute	661	223	66	2.96	10.0
7. Minnesota	2329	414	88	5.63	26.5
8. Missouri	645	278	22	2.32	29.3
9. Nebraska	486	191	15	2.54	32.4
10. Ohio State	1808	591	101	3.06	17.9
11. Oregon State	313	79	7	3.96	44.7
12. Pennsylvania State	566	267	31	2.12	18.2
13. Purdue	515	101	14	5.10	36.8
14. Rutgers	204	46	16	4.43	12.7
15. Wisconsin	1523	425	142	3.58	10.7

* Data from Circular No. 183, U. S. Office of Education. Correspqnding data for preceding four years in No. 149, 168, 172 and 176.

Still more surprising is the fact that, as shown in column (9), the total number of degrees in science remains about 55 percent of the total number in all subjects. I believe that the small increase with time shown in column (9) is real and that, if this column were extended back to 1911, the trend would be still more pronounced. The number of degrees in physics given at Berkeley has increased from about 4 percent of the total number in all institutions to about 5.5 percent. During the year 1939–40 we gave 14 degrees, and we expect to average about 12 degrees a year for the next few years.

I shall not comment on the total number of institutions giving science degrees, column (3), nor on the total number giving physics degrees, column (5). The information of this character already discussed in connection with Table I is far more informing and significant.

The main conclusion to be drawn from Table II is that, during the past quarter century, there has been an enormous increase in the number of doctorates conferred, in all subjects and at all institutions, broadly speaking. The increase can therefore not be ascribed primarily to the popularity of any one subject or any one place. The trend is general. Of course, there are exceptions. Thus the increase in astronomy is only 50 percent, compared to a 500-percent increase for science as a whole. Zoology has stood still during the past 10 years, while physics has nearly doubled. The pace for all science is really set by chemistry, which has shown consistently three times as many degrees as physics. In number of degrees awarded, chemistry has always been in first place, among the sciences, and now physics is clearly in second place. These two subjects comprise 40 percent of all science degrees, or 47 percent if biochemistry is included.

Assuming that exceptions, such as astronomy and zoology, merely prove the rule, one can conclude only that the great increase in the number of doctor's degrees during the past quarter-century, in science and in the arts, is simply a reflection of the great increase in graduate enrolment. Only when we get down to the school years where attendance is compulsory do we find a decidedly different situation. In this latter case the attendance obviously depends primarily on the population of the country and on the birth rate. Whether too many students are now going to college, or whether too many are getting the doctor's degree is a question for sociologists to answer. I see no evidence that it is now more difficult for a Ph.D. in physics to get a position where he can use his professional knowledge than it was in 1913, when I finished my own graduate work. Hence, so far as available positions are concerned, there is now the same abundance, or lack of abundance, of Ph.D.'s in physics as there was 27 years ago. The actual number of such men is, however, six times larger, as we have just seen, and the distribution among different types of professional positions is certainly changing. I will return later to this last remark.

Tables III and IV contain data from which it is more difficult to draw valid conclusions. The data refer to the single year 1938–39, for the 15 land-grant institutions, out of a total of 52 such institutions, that have awarded the doctor's degree in physics, as shown in Table I.

Table III lists the total graduate enrolment, the total number of master's and of doctor's degrees conferred, the number of graduate students per master's degree conferred (column 5), and finally, the number of graduate students per doctor's degree conferred (column 6). The results given in this final column are in general quite meaningless, without further information. The large value (62.1) of the ratio for the University of Kentucky, for instance, is caused by the fact that very few graduate students at Kentucky eventually get a doctor's degree, presumably because of lack of adequate facilities for such advanced work, although a large number get a master's degree. On the other hand, the large ratio (33.8) for the University of California results in part from the presence of a very large number of graduate students working for the general secondary teaching credential. California was the first state to require a fifth year of work for such a credential, and is still one of the few states with such a requirement. Furthermore, any graduate of an accredited institution may undertake graduate work at the University of California, although he cannot become a candidate for a higher degree except with the permission of the department concerned and of the dean of the graduate division. Other institutions, es-

pecially certain private institutions, rigorously limit enrolment in the graduate division to carefully selected students. That is one penalty that the state university must pay; everyone may come, but everyone may not demand a degree, and the slaughter is sometimes great.

Furthermore, everyone may come, but everyone need not be given a teaching assistantship. Less than half of the graduate students in physics at Berkeley hold such assistantships, whereas nearly every graduate student in physics does, I am told, at certain institutions. All such matters affect the size of the ratios given in column (6). In other words, from the relative size of this ratio, one can in general draw practically no valid conclusion regarding the scholastic standing of the institution. I will refrain from commenting in any detail on the fact that it is undoubtedly easier to get a doctor's degree at some institutions than at others—especially in certain subjects. This situation is buried in the figures of Table III and for the sake of national comity may well remain buried.

The data of Table IV are even more difficult to interpret correctly. The columns of interest here are the last four, giving, respectively, for the year 1938–39, the budget in dollars per student enrolled, the property value per student, the value of the equipment per student and the number of students per staff member. The budget includes all items except special capital expenditures on the physical plant. The property value includes everything. Both the staff and the total enrolment refer to the regular session and exclude summer session, extension classes and correspondence courses.

In the fifth column, the large figure ($1274.47) for the Massachusetts Institute of Technology undoubtedly reflects the fact that it is far more costly to give a student technical training than to give him a general academic training. The almost equally large figure ($1193.90) for Cornell University must be due primarily to the same cause, for only 26 percent of the students at Cornell are undergraduates in Arts and Sciences, whereas 51.5 percent of the students at California fall in that category. In spite of this fact, the Cornell figure is surprisingly high. The relatively low figure ($501.49) for California is chiefly a proof of the fact that mass education is cheap. Thus the data in this column show an appreciably larger cost per student in the case of several institutions whose facilities, viewed from any angle, are far inferior to those at other institutions, but whose total enrolment is much less. For instance, it takes no more teacher-hours to lecture to a class of 300 or 400 than to one of 50 or 100. It does require more student help, in the form of teaching assistants and readers, but such help is relatively cheap. The University of California is of the opinion that it is very foolish, from every standpoint, to force a professor to do

TABLE IV. *Land-grant institutions, 1938–39.**

(1)	(2) TOTAL RESIDENT STAFF	(3) TOTAL ENROLMENT	(4) TOTAL BUDGET	(5) BUDGET PER STUDENT	(6) PROPERTY VALUE PER STUDENT	(7) EQUIPMENT PER STUDENT	(8) STUDENTS PER STAFF MEMBER
1. California	2219	27,551	$13,816,829	$ 501.49	$ 2943.	$521.46	12.4
2. Cornell	1078	7,055	8,420,584	1193.90	7353.	832.38	6.5
3. Illinois	1724	14,648	8,014,316	547.12	2292.	584.15	8.5
4. Iowa State	515	6,795	3,885,492	571.82	2055.	449.12	13.2
5. Kentucky	317	4,065	2,686,629	660.92	1730.	310.70	12.8
6. Massachusetts Institute	519	3,093	3,941,937	1274.47	17210.	659.54	6.0
7. Minnesota	1228	17,250	9,595,154	556.24	3090.	502.24	14.0
8. Missouri	431	6,445	4,399,225	682.58	2283.	622.05	15.0
9. Nebraska	441	7,210	3,361,870	466.28	1904.	498.06	16.3
10. Ohio State	809	14,368	6,882,136	478.99	1827.	474.32	17.8
11. Oregon State	319	4,835	2,447,791	506.26	1808.	429.67	15.2
12. Pennsylvania State	601	7,292	5,374,778	737.08	1670.	189.82	12.1
13. Purdue	453	7,098	4,412,333	621.63	2347.	311.87	15.7
14. Rutgers	462	3,773	3,542,603	938.94	5395.	273.93	8.2
15. Wisconsin	632	12,134	7,892,926	650.48	1825.	426.24	19.2

* Data from Circular No. 183, U. S. Office of Education. Corresponding data for preceding four years in No. 149, 168, 172 and 176.

50-cents-an-hour work; and as a result we have sufficient clerical, mechanical and student-assistant help to relieve us of such work. I have been really shocked at the conditions at many institutions, where professors who are paid at the rate of several dollars an hour for every hour they devote to university work of any kind, spend much of their time on work that could be done just as well, or even better, by others, at a cost of 50 cents to $1.00 an hour. There is evidently some basis for the prevalent belief that the average educational institution is perhaps the most inefficiently run of any type of institution in this country.

I do not wish, at this time, to enter into a detailed discussion of the relative merits of large and small classes, from a pedagogic point of view. The evidence thus far gathered on this question appears to be inconclusive; and for the average state institution, with its limited budget, a policy of small classes, including lecture sections, such as is in effect, for instance, at Yale, is simply out of the question. I will say, however, that it appears to me personally that if a large lecture section (even one as large as 300 or more students, as we have at Berkeley) is in charge of a really able lecturer supplied with an abundance of suitable lecture experiments, and meets in a properly lighted and acousticized room, the results are superior to those in the case of a small lecture section, when any one of the conditions just mentioned is lacking. I am surprised at even the poor quality of the blackboards found in many, possibly in most, classrooms. The point I am making here is that the size of the budget is important, but the way it is spent is equally important. This applies to the training of Ph.D. students as well as to undergraduate instruction. The last three columns of Table IV furnish additional evidence along these same lines.

Turning now more directly to the title of this paper, I note first that numerous articles bearing on the subject of student training and opportunities have already appeared in this journal. Most of these papers, to be sure, have to do with undergraduate work, but the training necessary in the graduate division depends directly on the amount and character of the previous training of the student. Hence undergraduate and graduate training should form an integrated whole, so far as the prospective Ph.D. in physics is concerned.

It is not convenient to list all of the pertinent papers, but I should like to mention specifically those by G. P. Harnwell,[2] A. R. Olpin[3] and H. L. Dodge,[4] as well as two reports[5] of the A.A.P.T. Committee on the Training of Physicists for Industry. Related to these two reports is a series of papers[6] by E. C. Crittenden, H. G. Dorsey, E. O. Hulbert and C. H. Kunsman, on opportunities for the physicist in various phases of government activity.

I conclude this list with two papers that I have found extremely interesting, one by John Satterly,[7] and the other by Richard Tolman.[8]

Tolman writes, "I think we must make a genuine attempt to secure both the mastery of a discipline and a substantial contribution to knowledge." I take that as my definition of the required training of the prospective Ph.D. in physics. As regards the research part of this program Tolman also writes,

> I think that we can regard the research as satisfactory, first, if it makes a substantial contribution to knowledge and, second, if it starts the candidate on a career of significant further discovery or application. . . . The university can control the second of the requirements only by waiting to see what happens to the man. In this respect the results are often very disappointing. Professor Bell, the mathematician, tells me of a twenty-year period in a great American mathematical school which provided graduates in mathematics, only 12 percent of whom ever published a single article after their doctoral thesis.

The article by Harnwell[2] bears so directly on the subject that I wish it could be incorporated

[2] Harnwell, "Graduate preparation for a career in physics," Am. J. Phys. (Am. Phys. T.) **5**, 97 (1939).
[3] Olpin, "Training of physicists for industrial positions," Am. J. Phys. (Am. Phys. T.) **5**, 14 (1937).
[4] Dodge, "Training of physicists for industry—from the point of view of the educator," Am. J. Phys. (Am. Phys. T.) **4**, 167 (1936).
[5] "Suggested four-year curriculum leading to the Degree of Bachelor of Science," Am. J. Phys. (Am. Phys. T.) **6**, 82 (1938); "Suggested four-year curriculum leading to the major in physics," Am. J. Phys. **8**, 124 (1940).
[6] Am. J. Phys. (Am. Phys. T.) **7**, 148–163 (1939).
[7] Satterly, "Observations on the objectives and the teaching of physics in England and Canada," Am. J. Phys. (Am. Phys. T.) **7**, 1 (1939).
[8] Tolman, "Remarks on the doctor of philosophy degree," Proc. 40th Annual Conference of the Association of American Universities (1938).

in full as a portion of this paper. In general I agree emphatically with Harnwell's remarks. One of our few points of disagreement will be mentioned in a moment.

Turning now to the preparation of physicists at the University of California, I note that our elementary course is two years in length, 3 credit units per semester, and is the course required for engineering students. This is a much more intensive presentation than the one-year course given for premedical students. Both courses are far more difficult than the descriptive course that we give for students who wish merely to satisfy the general science requirements of the University. It is our experience that, unless the elementary work can thus be divided into courses of varying magnitude and character, it is not possible to make the work satisfactory for *any* group.

The work of the major in physics, during the junior and senior years, is essentially a repetition of the elementary work, with merely further elaboration and intensification. It consists of advanced courses in analytic mechanics (6 semester hours), physical optics (3 hours), electricity and magnetism (4 hours), introduction to atomic structure (3 hours), and introduction to quantum mechanics (2 hours). These are the required courses in physics. A required 6 semester-hour course in differential equations and related topics completes the major. Most of our students also take a 3-hour course in heat, a 3-hour course in vector analysis, and a one-hour course in electrical measurements, which is now being converted into electrical measurements in the field of modern physics. Graduate students coming to us without these latter courses are normally required to take them. There are also upper division courses in sound, geometrical optics, discharge through gases, and in radioactivity and nuclear structure. We have, however, tried to hold our courses to a minimum, because of budgetary considerations; in fact, our present upper division courses total only 37 semester hours, as compared to the 40 hours that we offered 20 years ago.

Advanced laboratory work is given only in geometrical and physical optics, and in electricity and magnetism. In the distant past it was the policy of the department to start able students as early as possible on original experimental work rather than to load them with advanced laboratory work. Now, because of limitations of space, we are unable to extend our advanced laboratory work, even if we so desired. Since the time of the student is strictly limited, any additional work of this character must necessarily subtract from something else, and we believe that we already require enough technical work of a letters and science student. The curriculum for the four- or five-year course, suggested for the training of industrial physicists by the A.A.P.T. committee[5] and by Professor Dodge[4] is a rigidly prescribed curriculum, consisting almost entirely of professional courses. In the case of a Ph.D. student in physics, I still favor a certain amount of cultural work in the undergraduate years, with intense specialization reserved for the graduate work.

I note with interest that everyone recommends more work in English. The ability to express oneself logically, clearly and concisely is a major requirement in scientific writing, but an ability possessed by all too few students of science. I must say, however, that in my opinion the way to learn good English usage is to *read* good English rather than to take formal courses in the English Department. Try, for instance, that master of English, Robert Louis Stevenson.

To obtain a Ph.D. degree in physics at California, the student must satisfy two requirements, (1) pass a series of oral examinations, constituting collectively the preliminary examination for the doctor's degree, and (2) complete a satisfactory thesis. We give four preliminary examinations in physics and one in mathematics. Each is given by a permanently constituted subcommittee of three staff members. Each of the four examinations in physics covers one main field (*viz.*, mechanics, optics, heat, and electricity and magnetism), and in preparation for each, the student normally takes one graduate course. These more or less required courses in physics total only 19 semester hours and, hence, do not consume an undue amount of the student's time. Graduate courses in mathematics are also taken, but the amount and character of such work varies with the interests of the individual student. The same thing is true of work in other related departments.

Professor Harnwell appears not to think very highly of the preliminary examination. Here I differ with him. Our preliminary examination is on a whole field and is oral. A course examination is on a restricted portion of the field and is written. The two are completely different. A hard-working but relatively weak student can often make a fairly good showing on a written examination that is confined to certain specified topics. A properly conducted oral examination will indicate immediately whether a student has any true scientific understanding, as contrasted with memorized knowledge. There was a time when almost any graduate student, by hanging around long enough, could get a doctor's degree. That time is no more, as far as we are concerned. The preliminary examinations form the barrier that eliminates the weak student before he has gone very far into research work and, hence, before he has cost the department any great amount of time and money. A student is practically never failed on the final doctor's examination, which, at Berkeley, is confined to a discussion of the thesis and related topics. Hence, if the preliminary examination is not used as a real barrier, it means that the only requirement for the doctor's degree becomes effectively the completion of a satisfactory thesis. It should be admitted, in this connection, that conditions in a department with nearly a hundred graduate students are quite different from those in a department with a very small group. In the latter case, each member of the staff may be so intimately acquainted with each prospective candidate that formal examinations may well be reduced to a minimum.

In addition to the standard graduate courses already noted, we have many additional specialized courses, taken by students interested in the special field. We also have numerous seminars, both formal and informal. I agree with Professor Harnwell that these constitute the most stimulating portion of the student's training. At one informal conference of this nature at Berkeley there is an average attendance of over 60 persons, one-third of whom hold a doctor's degree. The inspiration of such a gathering cannot be exaggerated.

I have been asked to contrast the training of our graduate students now and in the past. I doubt, however, if there are any fundamental differences, although there are numerous specific changes. We believe that every student should be given a thorough grounding in the fundamentals of physics, regardless of his expected future occupation. Everyone apparently does not agree with this policy. At least we have had all too many students from elsewhere who had taken several courses—obviously more or less overlapping—in a certain field of physics, but who had taken no advanced work whatsoever in some other large and important field of physics. Here, however, we enter on a very broad subject, that of specialization *versus* a broad background, and I shall confine myself merely to the foregoing statement of our local practice.

There is little that need be said regarding the thesis. This is a matter that is arranged personally between the student and the professor. Because of the high level of specialization that now obtains in physical research, it is almost imperative that student research be confined to those lines of work for which the department has the necessary equipment, and to those subjects in which really expert knowledge is available in the department. Here the large and distinguished department has all the advantage, and it is obvious why most doctor's degrees are taken at a relatively few institutions.

It is often stated that the complexity of scientific research has now become so great that the Ph.D. candidate, in the course of his thesis work, really gets little beyond the stage of learning the required technic. It is only after being awarded the degree that he is more or less prepared to do worth-while research. There is much truth to this point of view, and just because of it, one cannot but feel sad that so many Ph.D. men have no real opportunity to continue their research. This brings us to the final announced topic of the paper—what sort of a position may the Ph.D. in physics hope to get?

I shall give you merely our experience at the University of California. Up to January, 1940, we had granted 118 Ph.D. degrees. So far as we know, only one of these persons is deceased. Evidently the field of physics is a fairly healthy one! These 118 persons hold positions, or held them at the time of retirement or death, distributed as follows:

Teaching	
University	44 (37.3 percent)
College	20 (16.95 percent)
Junior college or technical school of that grade	7 (5.9 percent)
State teachers' colleges	3 (2.55 percent)
Full-time research	
Industry	20 (16.95 percent)
Government	10 (8.5 percent)
Academic	7 (5.9 percent)
Astronomy	2 (1.7 percent)
Other fields	5 (4.2 percent)

Thus there are 74, or 62.7 percent, engaged in teaching, and only 37.3 percent engaged in all other activities. Most of the 7 in academic research are engaged with cyclotron construction and operation. It is noteworthy that only 4 percent are working in "other fields." Of the 118, 36 are employed in the state of California, and 82 outside the state.

Although most of our graduates have gone into teaching, one may not draw any particularly significant conclusions from that fact. Most of the members of our staff are interested primarily in teaching and in what is called pure scientific research. I presume that as a consequence there is a natural tendency for our students to go into the same lines. However, I should like to state as emphatically as possible that we draw no invidious distinctions between mathematical physics, pure experimental physics, and applied or industrial physics. To make such distinctions is pure intellectual snobbery.

As one may note from the articles already cited,[3–5] there is a definite movement under way to introduce a specialized course preparing men for industrial research in physics. It does not seem possible to introduce such a course at Berkeley at the present time, but I think that there are important arguments in favor of giving all Ph.D. men essentially the same training, just as we do now.

The average student, when he enters the university, is not very certain as to what his major subject will be. Similarly, the average physics major, on starting graduate work, is not very certain as to the special field of physics in which he will do his research, and he is still more uncertain (and necessarily so) as to the sort of position he will eventually obtain. All too often the position he actually has an opportunity to accept, and does accept, is not exactly what he may have hoped to get. Under such circumstances the most logical procedure seems to be that which we have adopted—namely, to give each graduate student a thorough knowledge of the fundamentals of physics, and a certain amount of specialized knowledge in the field of his research.

It is well known that employers of engineers, in answer to questionnaires, have invariably favored increased training in mathematics and in the fundamental sciences, physics and chemistry. Since increased time devoted to these subjects requires correspondingly decreased time devoted to regular engineering courses, it has usually been difficult to persuade professors of engineering to make the necessary changes. The point of view of the employer is that most specialized knowledge and technics must, necessarily, be learned "on the job." What the new employee *must* possess is a knowledge of the fundamentals of the subject. I believe that the same situation is true in connection with the training of physicists for industrial research. I also believe that most of us have an exaggerated idea of the amount of information that we can give and have given to our students. We should remember how difficult it has been for us to acquire a real understanding of the material we present in our courses. If a student, at the close of his university work, shows a clear understanding of the fundamentals of physics, we should be well satisfied.

So far as the present prospects of a Ph.D. in physics are concerned, there is no doubt that a greater proportion of our graduates are finding positions in industrial research, and in junior and other colleges, than was the case 30 years ago. (In fact, the first junior college in California was started just 30 years ago.) Conversely, a smaller *proportion* find positions in universities, although the *absolute* number of such positions is certainly much larger.

Men, however, differ in temperament and character, and to each different type of position there is a corresponding needed temperament. To get a position is one thing—to hold it is another. In the long run one must possess not only the necessary technical knowledge but also the necessary temperament. And above all else one must possess high personal character, for character, after all, is the most important thing in the world.

Secondary School Mathematics in Relation to College Physics

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THE problems of mathematical instruction in elementary and secondary schools are of great professional importance to the physics teacher. In particular, the physics instructor of collegiate standing is much interested in the following question: "*Is the mathematical equipment which the college freshman brings from the secondary school all that his teacher in physics would like it to be?*" Specific as this question is, it is an organic part of the wider problem of secondary and elementary education in general and cannot be treated aside from the broader educational trends prevailing in our schools. In view of the complexity of the subject, the present paper does not claim to offer an exhaustive analysis but merely attempts to serve as a starting point for its further discussion.

It is a well-known fact that the dominant point of view in contemporary education is that of the so-called practical or pragmatic philosophy. Seen from this vantage point, the purpose of the schools is to help the students in the absorption and interpretation of experience. Many educators maintain, therefore, that knowledge should not be imparted in abstract form but only through its practical applications. It must be admitted that it is sound educational policy to point out, wherever possible, the practical utility of the teaching material. It is well to show the students that the subject matter is not cut and dried but alive and valuable insofar as it is helpful in dealing with the everyday problems even of their limited world. This goes a long way toward keeping up their interest and making the process of learning easy and pleasant. However, the modern educator should beware of a one-sided exaggeration of the pragmatic approach to the exclusion of every other method of instruction. The danger of such an overestimation is heightened by the name *progressive education*, which has been given to the several systems of teaching that try to carry pragmatism into effect—a name which suggests that these trends are entirely new and modern. Certain secondary features of the progressive systems are really novel and highly commendable in their tendencies: in the relations of the pupils with their teacher, they are intended to moderate discipline by comradeship; in the relations of the pupils with one another, to replace the competitive spirit by the spirit of teamwork. These are praiseworthy endeavors, although the success of the present schemes for their realization is not yet beyond question. However, the primary essence of the so-called progressive education, *its utilitarian character and insistence on practical application*, is neither new nor modern. William James, the founder of pragmatic philosophy, described it as "a new name for old ways of thinking." This description is particularly apt in relation to pragmatic education whose roots lie in the pioneer psychology of the last century. In the face of a vast, untamed continent the emphasis of the pioneers lay naturally on action. Lack of time and personnel in the little red schoolhouses were compelling reasons for sacrificing all long-range aims of instruction to its immediate utility.

Having given praise to the advantages of progressive education, we must also mention the drawbacks which may manifest themselves in elementary and secondary mathematical instruction. The extreme stress on teaching through applications may lead to some undesirable features, which we shall now discuss. In the first place, the emphasis lies on the practical side and not on the underlying principles, on *how to do things and not how to reason them out*. Altogether too often we meet teachers who—without fully explaining its derivation—merely give the students a formula for the solution of a certain type of problems and assign to them 40 or 50 problems for exercise. Attempts by the pupils to solve these problems in their own way are not only discouraged but strictly forbidden. Teachers of this sort have, in our opinion, a completely wrong view of the function of mathematics in education. Indeed, we may ask: "Is the knowledge of how to give change, how to compute percentages or how to calculate the heights of mountains a sufficient compensation for devoting to mathematics one's adolescent years?" We think this is open to serious doubt. Mathematics

is a valuable part of the curriculum because it offers a wonderful opportunity for developing the powers of logical reasoning—powers which once acquired remain, when many of the rules of arithmetic and all the theorems of geometry are long forgotten.

The reader will have noticed that we are touching here upon the so-called problem of *transference of training*, the question whether practice in one kind of mental operations is of any help in acquiring the mastery of another kind. The experienced educators have always claimed that the answer to this question is in the affirmative, that the popular phrase of "improving the mind" has a basis in fact, and that it should be the highest aim of general education. For a few years, this contention was questioned by psychologists whose findings seemed to show little or no transference. However, as the conditions of the psychological experiment were diversified, it was found that the negative result of the early investigations was due to a choice of experimental conditions having but little analogy to schoolroom situations. Experiments designed in sufficient conformity to schoolroom practice to have a bearing on education gave an entirely different result. One of the most careful and comprehensive investigations in this connection is due to H. Woodrow,[1] who states his conclusions in the following words:

> The experiment shows that in a case where one kind of training—undirected drill—produces amounts of transference which are sometimes positive and sometimes negative, but always small, another kind of training with the same drill material may result in a transference, the effects of which are uniformly large and positive . . . the difference between unenlightened drill and intelligent teaching.

This is exactly the point that we are trying to make: mechanical application of rules and formulas is worthless for the development of the reasoning powers, but a systematic instruction in mathematics may be of great benefit for it.

This great opportunity is thrown away by those teachers who conduct their classes in the mechanical parrot-like way described above. But this is not all: *the utilitarian adjustment of the instruction to special problems defeats its own purpose*. When the type of problem is but slightly changed, the pupil is completely helpless. As the little daughter of some friends of mine remarked to me: "Oh yes, I know arithmetic very well. I know how to divide and how to multiply. The only thing I don't know is when to divide and when to multiply." It is remarkable that people in practical life engaged in training for gainful professions do not believe in teaching through applications only. The singing teacher, the athletic coach make their students go through long and arduous preliminary work before permitting them to engage in practice. A few years ago I happened to visit the scientific laboratories of a large industrial plant and was struck by the apparently nonutilitarian character of the research work there in progress. Being introduced to one of the heads of the firm, a vice president in charge of sales, I complimented him on the excellence of the laboratories and mentioned that I saw there only pure science, the same kind that we carry on in universities. The businessman smiled and answered:

> It turned out to be the best policy to let the scientists work in their own way. They dig at the roots of the phenomena. When they understand the fundamental principles involved, it is for them child's play to deal with any practical applications that may come up. The scientific laboratories give us not only prestige but profit; they have paid for themselves scores of times over.

Another undesirable feature of teaching through applications lies in the fact that information is imparted *as opportunity arises*—often in a haphazard way. Unless the teacher is exceptionally skillful, the instruction remains one-sided and incomplete in that the different parts of the subject matter seem to stand by themselves and their interdependence is not brought out. The subject matter appears to the student as a series of disconnected rules and not as a unified science. In this unsystematic procedure some topics are apt to be left out altogether, especially those that seem to the pupils difficult or uninteresting. We have already mentioned that it is well to make the instruction as easy and interesting as possible. This principle is now recognized so universally that we are apt to forget that in former times it was in question. A hundred years ago the English philosopher James Mill ridiculed

[1] H. Woodrow, J. Ed. Psy. **18**, 159 (1927).

endeavors to make instruction easier with the words: "Next, they will be inventing schemes to make prayer easier." Fortunately the times are past when education was considered exclusively from the point of view of discipline, and the mental comforts of the pupils were entirely disregarded. In mathematics the efforts to enlist the interest of the students have begun earlier than in other subjects, but there is still room for improvement. For instance, many of the problems could be taken from the hobbies and activities of the adolescent and so be brought nearer to his sphere of interests.

However, trying to make a subject palatable to the pupil by sparing him boredom from unnecessary abstractions is one thing; and cutting out whole parts of the curriculum which seem unattractive, although they may be indispensable for a complete understanding of the whole, is another. Such a policy is short sighted because it protects the pupil from slight mental discomforts in the beginning at the expense of more formidable difficulties in the end. The interest of the adolescent is mightily stirred when the different bits he has learned begin to fall into place and mathematics reveals itself to his maturing eye as a united and harmonious structure. On the other hand, his interest must necessarily flag if such an integration of his knowledge is made impossible and what should be an edifice remains to him a pile of bricks.

I have emphasized the evils of a one-sided exaggeration of pragmatism for the reason stated in the beginning: because this philosophy is part and parcel of our contemporary school policies. In fairness to the secondary school teachers I must say, however, that the extreme cases described by me are apt to occur far oftener in elementary than in secondary schools. The tendencies of progressive education affect the teaching of geometry, algebra and trigonometry in a lesser degree; but if their influence is here weaker, it is by no means negligible. Thus the preceding discussion has a twofold bearing on the specific question in which we are most interested—the adequacy of secondary school teaching for college needs. In the first place, arithmetic is the foundation of all mathematical teaching. Therefore, faulty instruction in arithmetic in the lower grades may impede the effective teaching of more advanced mathematics in the higher. The harm done in the elementary school is but slowly and painfully repaired in the secondary. If it is undone incompletely, it comes to the attention of the college instructor. In the second place, the lack of balance between applications and fundamentals occurs in the teaching of arithmetic in its most virulent manifestations described above. Here the virus can be studied, so to speak, in its pure culture; but the same problem presents itself often in a milder and less obvious form in the teaching of the higher branches of mathematics. In this case the conditions are even more complicated because not only two but fully three aspects of the subject vie for the attention of the teacher. The three-cornered rivalry lies between, first, the practical and numerical applications and examples; second, the formalistic drill or so-called mathematical technic; third, the conceptual foundations and basic logical connections. The question is: Do all three aspects receive sufficient attention, and how much time should be devoted to each?

The pragmatic tendencies of our time favor the numerical applications which bring in relief the utility of mathematics. Therefore, the treatment of this aspect is everywhere adequate or more than adequate. The secondary educators have become aware also of the broadening influence of the conceptual foundations and of that class of problems which are not so much concerned with the mechanical application of a formula as with reasoning out which formula to apply. Some of the larger high schools are conducting special courses for more gifted students in which the logical connections are particularly stressed. Both these phases of mathematical instruction are of general educational value: the second, *directly* because it sharpens the mind and develops the powers of logical reasoning; the first, *in a subsidiary way*, as it helps to maintain the student's interest and gives him a feeling of accomplishment.

It is different with the third aspect, *the mathematical technic*, meaning by this the skill in the transformations, reductions and simplifications of mathematical expressions. Only the student who intends to go into higher mathematics, physics or engineering needs this skill, but then he needs it badly. It has not much general

educational value but it happens to be the prerequisite in which the collegiate teachers in physics and calculus are most interested. This is another example of the naïve and oversimplified way in which the progressive theories of teaching through experience approach highly complicated questions; precisely the students of engineering who want to use mathematics as the tool of their profession must be versed not so much in the numerical applications of algebra and trigonometry as in something that appears to the outsider to be an idle intellectual game.

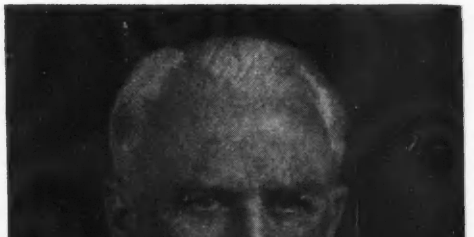
The only complaint about secondary school mathematics which I have heard in my many conversations with freshman instructors is of an insufficient training in mathematical technic. In all other respects they find the preparation of the students good or, at least, adequate. The deficiency in mathematical skill manifests itself particularly in trigonometry. The high school exercises are devoted mostly to the solution of triangles and similar numerical problems, while from the point of view of the physicist training in transformations of formulas would be preferable, supplemented by problems involving the interrelations of the different trigonometric functions, their addition theorems, and other properties. In a lesser degree similar considerations refer to algebra. A little more experience in the manipulation and transformation of algebraic expressions would give a great advantage to the college freshman bent on the study of calculus.

In a most gratifying spirit of cooperation mathematics departments of the high schools in our locality begin to meet these desires. The Pasadena Senior High School is offering now two types of courses in trigonometry. The one emphasizes the calculation of triangles and is primarily designed for those students who prepare for surveying; the other stresses the trigonometric functions and is meant for those who intend to go into physics and engineering. This division solves the problem in a most satisfactory way; its general adoption by the larger high schools would, certainly, find the cordial support of the collegiate instructors. The situation is more difficult in smaller schools which have not enough personnel to offer two courses. The majority of the students are not preparing themselves for the study of physics or engineering and they have no use for the tricks of mathematical sleight-of-hand. We have already expressed the view that the primary function of school mathematics is to teach the students how to use their reasoning abilities, and we have seen that this view is supported by the findings of modern experimental psychology. If it be accepted, then it is possible to argue that the students of average mathematical ability, who constitute the majority, are benefited by a thorough instruction in mathematics fully as much as the few gifted ones, provided the instruction emphasizes fundamentals of logic rather than mathematical technic. The curriculum, of course, should be adjusted to the needs of the majority, but there is no reason why students who are willing to go beyond the requirements of the course and who wish to exercise their superior gifts by working special problems should not be allowed and encouraged to do so. The special problems assigned to them should be of the kind developing mathematical technic.

The question may be raised as to how the college teachers of physics could make their influence felt. The first step toward this would be to make their desires—with respect to the secondary teaching of mathematics—articulate and precise. The American Association of Physics Teachers is aware of the importance of the problem and has devoted at least one of its sectional meetings, on the Pacific Coast, to a discussion of it. The practice of publicly threshing it out in meetings and in periodicals should be continued and supplemented by the appointment of standing committees charged with drawing up a detailed list of desiderata. There will be no difficulty in obtaining the cooperation of the secondary schools. The relations of the California Institute of Technology with the mathematics departments of the neighboring secondary institutions always have been most pleasant; any suggestions with respect to mutual needs have been treated with sympathy and understanding. But, when the collegiate physics teachers have a concrete program backed by the majority of the profession, they will be able to obtain the consideration of their wishes even in elementary schools.

Robert Andrews Millikan

Recipient of the 1940 Oersted Medal for Notable Contributions to the Teaching of Physics



The American Association of Physics Teachers has made the fifth of its annual awards for notable contributions to the teaching of physics to Robert Andrews Millikan, Director of the Norman Bridge Laboratory of Physics and Chairman of the Executive Council of the California Institute of Technology. The addresses of recommendation and presentation were made by Professor Duane Roller and Professor Richard M. Sutton in a ceremony held on December 30, 1940, during the tenth annual meeting of the Association at Philadelphia, Pennsylvania. In Professor Millikan's absence, the medal was accepted on his behalf by Dr. Carl D. Anderson, and the address of acceptance prepared by Professor Millikan was read by Professor Frederic Palmer.

Address by Professor Duane Roller

ROBERT ANDREWS MILLIKAN'S career is in rather striking contrast to the conventional career in science in that he devoted the early years of his professional life mainly to teaching and to reforming the teaching of physics at the college and university levels. Instead of being chiefly an investigator of pure science, with teaching as a side line, he was primarily a teacher during this phase, although at the same time working, as is now apparent, toward fundamental research.

Beginning his professional life at Oberlin College, where he served as tutor between the times when he received the A.B. degree, in 1891, and the master's degree, in 1893, MILLIKAN proceeded to Columbia University as a fellow, was awarded the doctorate there in 1895, and then engaged in a year of study at the universities of Berlin and Göttingen. In 1896 he went to the then new University of Chicago as an assistant in physics under MICHELSON, and remained there for 25 years, serving almost half of that time in the capacity of full professor. At that institution he played a leading part in the teaching of physics,

both undergraduate and graduate. During this period the department at Chicago came to supply a large fraction of the physics teachers of college and university grade throughout the middle western states, and a list of physicists in that region often read like a list of MILLIKAN's students; this was also true of a large fraction of the physicists in industry whose training dates from this period.

MILLIKAN helped to initiate a wave of renewed interest in the science of physics when he established the experimental course at Chicago soon after his arrival there,[1] and the results of this work were widely disseminated by the publication of the two unique college textbooks, *Mechanics, Molecular Physics and Heat* (1901) and *Electricity, Sound and Light* (1908).[2] The reorganization of the undergraduate courses at Chicago was based on a close correlation between laboratory and classroom work, and it was around a series of experiments, which MILLIKAN insisted must be made significant and capable of yielding precise results, that these textbooks were built. Attempts to secure a satisfactory articulation of the laboratory and classroom phases of instruction were not prevalent at the time, although the objectives thus to be realized do not differ essentially from those that guided the pioneers of physics in training small groups of workers in the early laboratories; but MILLIKAN was convinced that this was the way in which the student could most readily gain genuine insight to the methods of physics and a thorough grasp of its foundation principles.

A break with the past was also urgently needed in secondary education at the time when MILLIKAN and GALE introduced *A First Course in Physics* (1906) into the University of Chicago High School. This book, which was supplemented by a laboratory course involving relatively inexpensive apparatus of simple but sound design, was one of the first, if not the first, of the modern high school textbooks in physics. It soon became standard, with an enormous circulation, and still is in wide use, having been revised in collaboration with several different teachers of secondary school physics. With its influence apparent in most of the current high school textbooks that have since been written, it has left its stamp indelibly on American physics teaching.[3] If the original edition of this textbook should now be regarded as providing only an interim stage, with some of the educational reforms typified by it apparently outmoded, this is merely because secondary education is progressing. Although the reforms in progress today are tremendously significant and will also leave their indelible stamp, the school science of the future, since it must be designed for a culture essentially much more scientific than the one today, will, of necessity, have the solid, scientific character that MILLIKAN has always advocated.

Although contributions to educational technic help to shape the course of education and may be of great assistance to other teachers, in the last analysis their value must be judged by their effects on students; hence it is in terms of his students that the real educational contributions of a teacher can best be evaluated. Few men have had contact with so many graduate students as MILLIKAN. Always he has been willing and anxious to have a large group of them working on a variety of problems. His method frequently has been of the "sink or swim" variety in which much is left to the student, but it would be difficult to imagine anyone more stimulating either by example or in actual contacts. Emphasizing and insisting upon close association of teaching and research, he has consistently opposed the employment of paid research-assistants on the ground that research can be carried out better on the basis of a teacher-student relationship. He has believed that the best introduction to laboratory procedure and technic is to be obtained by working under supervision on a significant research problem; and, conversely, that an enthusiastic graduate student actively

[1] *A course of college experiments in physics* (1898).

[2] *Electricity, sound and light* was written in collaboration with John Mills.

[3] Papers on school physics published or read by Millikan during this period include: "Present tendencies in the teaching of elementary physics," Sch. Sci. and Math. **6**, 119, 187 (1906); "Laboratory experiment upon the mechanical equivalent of heat," Sch. Sci. and Math. **6**, 310 (1906); "Experiment on the magnifying power of a single lens," Sch. Sci. and Math. **6**, 450 (1906); "Experiment upon cooling through change of state," Sch. Sci. and Math. **6**, 772 (1906); "Relation of high school and college physics," Eastern Association of Physics Teachers (Boston, 1908); "Function of the lecture demonstration in secondary school physics," J. of Proc. and Addresses, Nat. Ed. Assoc. 985 (1908); "Aims and needs of high school physics," Sch. Sci. and Math. **9**, 162 (1909).

engaged in study and research may be a better teacher in the lower-division college than a person with more experience but less interest and enthusiasm. A former colleague recently said this of him:

> We never had at the laboratory a more inspiring leader, nor do I ever expect to see another like him. Yes, like the rest of us, he has his foibles and weaknesses—and I have always loved him for these human traits especially. Personally I have never known him to be ungenerous or inconsiderate with anyone who is doing his part to the utmost in a cooperative job. He carries the torch of enthusiasm that lights fires in the younger men with whom he is in contact. If the torch is so combustible that his own fingers are sometimes burned by it, this to me has only endeared the individual.

In 1921, MILLIKAN left Chicago to become Director of the physical laboratory and Chairman of the Executive Council of the California Institute of Technology. There he has devoted much of his time to building a scientific institution with a strong research atmosphere, but again with the teaching function at the base of the organization. Consequently, he has insisted that a four-year undergraduate college be maintained, and not neglected, in this great productive center of scientific research; and his desire has been that all research men do some teaching and that all teachers engage in some research. An able and shrewd executive, he has not ceased to emphasize the significance of a faculty member as opposed to the administrator in an institutional organization. An indefatigable worker, now 72 years of age, he continues to maintain close contact with experimental work and still teaches a course every year.[4] His students refer to him as "The Chief." He is the chief, too, regardless of his democratic views on institutional organization; he could not be less, with his dogged determination and great self-confidence, traits that are part of the strength of the man, but that have, nevertheless, earned him critics as well as advocates, with only a few people lukewarm on either side.

Not to be overlooked is the part he has played in bringing the sciences to the attention of the American public. Through many public services rendered to nation and community, publications and lectures addressed to the laity,[5] and his experimental work itself, which has caught the popular fancy and is always "good news" in the journalistic sense, MILLIKAN has become a national figure, with his name almost synonymous with science in the public mind. To estimate the value of these contributions in terms of such factors as financial and moral support gained for scientific research and the general spread of scientific education is, of course, difficult; but we know that their value is extraordinarily high. Moreover, not MILLIKAN, but society and the scientific worker have ultimately been the real gainers as the result of these public activities.

It is in recognition of these many notable contributions and activities connected with physics education that PROFESSOR MILLIKAN has been awarded the Oersted Medal. He has received nearly half-a-hundred other medals, honorary degrees and memberships in honorary societies, but most of them have been in recognition of his more purely scientific contributions. Since the latter have often been described elsewhere, we will merely remind ourselves that they include such fundamental studies as the isolation of the electron, and measurement of its charge, the photoelectric determination of the Planck constant, the wide extension of the ultraviolet spectrum to the region of soft x-rays, and the investigation of the nature and properties of cosmic radiation. His experimental papers must number in the hundreds.

MILLIKAN has been characterized as "ten men in one."[6] Now most physical experiments and apparatus also have this many-in-one character, being capable of yielding or testing a variety of results having all sorts of ramifications; and even our equipment for teaching is often as versatile as that well-known electrical set which, according to the catalog description, "by the interchange and substitution of dynamo parts and the addition of accessory pieces . . . the necessary ap-

[4] Recent textbooks of which Millikan is a co-author are: *A first course in physics for colleges* (1930), *New elementary physics* (1936), *Mechanics, molecular physics, heat and sound* (1937).

[5] Various articles in *Scribner's Magazine*, *Yale Review*, *Atlantic Monthly*, *Quarterly Journal of Science*, *Religion and Philosophy*, *American Education*, *School and Society*, etc., during the period 1923–1939. Also the following books: *The electron* (1917), *Science and life* (1923), *Evolution of science and religion* (1927), *Science and the new civilization* (1930), *Time, matter and values* (1932), *Cosmic rays* (1939) etc.

[6] J. Janney, Am. Mag. **120**, 34 (1935).

paratus is quickly assembled for demonstrating, illustrating and studying all the fundamental principles of current electricity, from theoretical to commercial viewpoints." Thus, with seven-or-more-in-one apparatus on our lecture tables and evacuated machine shops in our laboratories, it seems most appropriate that we have a ten-in-one physicist in our distinguished group of Oersted medalists. We should like to lay part claim to the professional career of PROFESSOR MILLIKAN for purposes of demonstration; since, in the jargon of the apparatus catalog, by interchanging and substituting his contributions, and adding his accessory activities and traits, we may quickly assemble this career for demonstrating and illustrating to younger physics teachers the selection principles employed in choosing an Oersted medalist.

Presentation of Award by Professor Richard M. Sutton

The foregoing citation, delivered by a former student of DOCTOR MILLIKAN's, and a collaborator with him in the revision of two of his textbooks, is an objective statement of great accomplishments by a man whom we learned to love and respect as "The Chief" during our graduate days at the California Institute of Technology. Since DOCTOR MILLIKAN has found it impossible because of many duties to be present, he is represented at this ceremony by DR. CARL D. ANDERSON, also a former student, both as an undergraduate and a graduate, at the California Institute of Technology, and now a member of the faculty of that institution. He is one who in recent years has followed in the steps of his chief even to the extent of bringing to America another Nobel prize in physics.

On behalf of the American Association of Physics Teachers, I have the privilege of handing to DOCTOR ANDERSON this medal, named after HANS CHRISTIAN OERSTED, a great teacher and a great investigator, and this certificate of award, begging that he will convey them with expressions of our sincere respect and best wishes to DOCTOR MILLIKAN, whom we regard highly for his tireless efforts on behalf of science, his signal contributions to human knowledge, his stimulating influence as a teacher and enthusiast, and his sterling qualities as a leader and friend.

Reproductions of Prints, Drawings and Paintings of Interest in the History of Physics

14B. Paintings of Lectures at the Royal Institution: A Friday Evening Discourse on Liquid Hydrogen by Sir James Dewar, 1904

E. C. WATSON
California Institute of Technology, Pasadena, California

IN addition to the Christmas Lectures at the Royal Institution, two other courses are regularly offered, the Afternoon Lectures and the Friday Evening Discourses. The latter, which are justly famous, are given at 9 o'clock each Friday evening from November until June. At that time a discourse "is delivered by some recognized authority, either upon some novel discovery, some recent development of scientific speculation, or some fresh aspect of a social, literary, artistic or scientific problem. These lectures are illustrated, so far as the subject permits, by experiments, diagrams and lantern slides. Interesting and sometimes unique exhibits, illustrative of some subject of current discussion, are arranged in the library, which is at the disposal of Members and their guests for social and conversational purposes both before and after the lectures."[1] As SILVANUS P. THOMPSON says in his biography of FARADAY,[2]

> The Friday night gathering is always a brilliant one. From the *salons* of society, from the world of politics and diplomacy, as well as from the ranks of the learned professions and of the fine arts, men and women assemble to listen to the exposition of the latest discoveries or the

[1] *Record of the Royal Institution of Great Britain.*
[2] *Michael Faraday, His life and work* (Cassell, 1901), pp. 38–39.

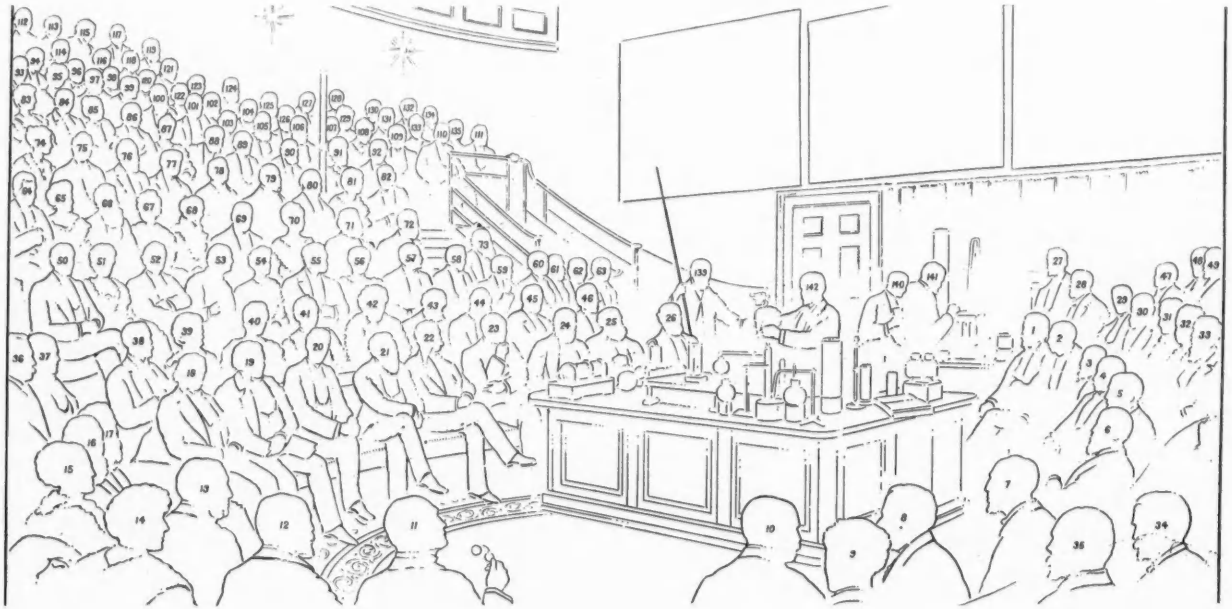


PLATE 2. KEY TO PLATE 1.

1 Sir David Salamons.
2 Sir Francis Galton.
3 Robert Mond.
4 Dr. J. Mitchell Bruce.
5 Maures Horner.
6 Sir Arthur Church.
7 Dr. Rudolph Messel.
8 W. B. Gibbs.
10 Arthur Rigg.
11 Sir James Stirling.
12 Sir J. Wolfe Barry.
13 The Duke of Northumberland, *President*.
14 Lady Rayleigh.
15 Lady Kelvin.
16 Lord Kelvin.
17 Sir William Huggins.
18 Lord Lister.
19 Sir Frederick Bramwell.
20 A. J. Balfour.
21 Sir William Crookes, *Secretary*.
22 Sir James Crichton Browne, *Treasurer*.
23 Lord Rayleigh.
24 George Matthey.
25 Dr. Ludwig Mond.
26 Sir Oliver Lodge.
27 Earl Cathcart.
28 J. B. Broun-Morison.
29 Commendatore G. Marconi.
30 Sir Hugh Bell.
31 Lady Huggins.
32 Mrs. Henry Pollock.
33 Sir John Aird.
33A Dr. E. Divers.
34 C. Vernon Boys.
35 Dr. J. Dundas Grant.
36 Sir Benjamin Baker.
37 Earl of Halsbury.
38 Sir George Darwin.
39 Lady Priestley.
40 Mrs. Ludwig Mond.
41 Lady Crookes.
42 Lady Dewar.
43 Lord Avebury.
44 Sir Andrew Noble.
45 Sir William Farrer.
46 Sir Felix Semon.
47 George Willoughby.
48 Francis Fox.
49 J. J. Vezey.
50 Edward Pollock.
51 Mrs. Edward Pollock.
52 Lord Alverstone.
53 Sir Alfred Kempe.
54 Lady Kempe.
55 Alexander Siemens.
56 Mrs. Alexander Siemens.
57 Lord Blyth.
58 Sir Edward Fry.
59 Lord Sanderson.
60 Dr. Donald W. C. Hood.
61 J. H. Balfour Browne.
63 C. Scott Dickson.
64 A. C. Ionides.
65 Mrs. Ionides.
66 Sir Joseph Wilson Swan.
67 Lady Swan.
68 Mrs. McClean.
69 F. McClean.
70 Mrs. Goschen.
71 Professor William Odling.
72 Dr. Thomas Buzzard.
73 Sir Alexander Binnie.
74 Mrs. West.
75 Dr. Samuel West.
76 Sir Philip Magnus.
77 Sir Francis Laking.
78 C. A. Parsons.
79 Sir William Preece.
80 Dr. Charles Beevor.
81 Mrs. Beevor.
82 S. F. Beevor.
83 Mrs. Dundas Grant.
84 W. R. Pidgeon.
85 Mrs. Pidgeon.
86 F. Clowes.
87 Mrs. Macnaught.
88 Sir J. Mackenzie Davidson.
89 Dr. W. J. Russell.
90 W. Hugh Spottiswoode.
91 Mrs. Palmer Thomas.
92 R. Palmer Thomas.
93 Shelford Bidwell.
94 P. F. Frankland.
95 Miss Meadows White.
97 J. D. Everett.
99 W. W. de la Rue.
100 Dr. G. Johnston Stoney.
101 Sir J. Fletcher Moulton.
102 George Herbert.
103 R. Meldola.
104 Sir William Abney.
105 Rosser Dean.
106 Lord Amherst.
108 Lady Cunynghame.
109 Sir Henry Cunynghame.
110 Sir Owen Roberts.
111 Sir William White.
112 Sir Frederick Pollock.
114 A. A. Campbell Swinton.
115 Dr. Woodhouse Braine.
116 C. Langdon Davies.
117 W. Adams Frost.
118 Roger Wallace.
121 Wilson Noble.
123 Miss Western.
125 The Earl of Rosse.
126 F. Lys Smith.
127 A. Henry Savage Landor.
128 H. Baldwin.
129 Mrs. Frank Lawson.
131 G. F. Chambers.
132 Charles Hawksley.
134 Sir Arthur Rücker.
135 Sir Alexander Mackenzie.
139 Richard Fowler.
140 J. W. Heath.
141 R. N. Lennox.
142 Professor Sir James Dewar.

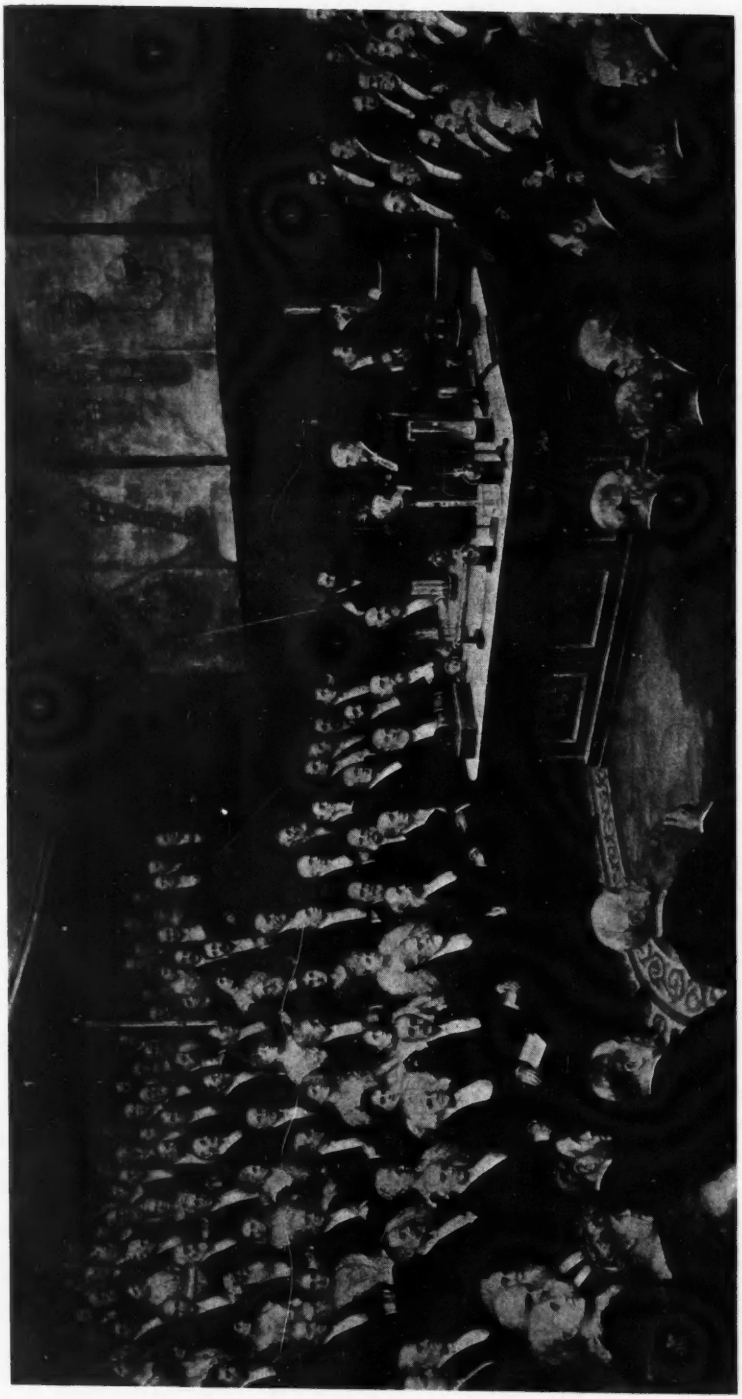


PLATE 1. SIR JAMES DEWAR LECTURING ON LIQUID HYDROGEN AT THE ROYAL INSTITUTION, 1904.
(From the painting by H. Jamyn Brooks which hangs in the rooms of the Royal Institution.)

25 Dr. Ludwig Mond. 30 Edward Pollock. 77 Sir Francis Laking. 105 Rosser Dean. 142 Professor Sir James Dewar.

newest advances in philosophy by the men who have made them. . . . No fee is paid to the lecturer, save a contribution towards expenses if applied for, and it is considered to be a distinct honour to be invited to give such a discourse. . . . Not infrequently, the person invited . . . will begin his preparations five or six months beforehand. . . . A mere enumeration of the eminent men who have thus given their time and labours to the Royal Institution would fill many pages. It is little cause for wonder then that the lecture-theatre at Albemarle Street is crowded week after week in the pursuit of science under conditions like these; or that every lecturer is spurred on by the spirit of the place to do his subject the utmost justice by the manner in which he handles it. There are no lectures so famous, in the best sense of the word so popular, certainly none sustained at so high a level, as the lectures of the Royal Institution.

One of the most noteworthy of these Friday Evening Discourses was that given by SIR JAMES DEWAR (1842–1923) in 1904 on liquid hydrogen. The scene was painted by H. JAMYN BROOKS, and the painting now hangs in the rooms of the Royal Institution. It is reproduced in Plate 1 and affords excellent likenesses of a number of the most famous men of science of the period, such as KELVIN, HUGGINS, CROOKES, RAYLEIGH, LODGE and many others. A key to the 142 figures portrayed is provided in Plate 2.

PROFESSOR H. E. ARMSTRONG has recorded[3] that DEWAR

was often an incoherent lecturer, yet his lectures were the most masterly and fascinating displays ever witnessed. He set a standard which has made the Royal Institution table remarkable throughout the world. Faraday was celebrated for the simplicity of his style—Dewar is to be thought of on account of the daring of his displays, the remarkable refinement and oppositeness of his demonstrations, all most carefully arranged and rehearsed in advance. He was a great scientific actor, playing plays with the most thrilling of plots and entirely original special scenery for each performance. His manner, his "brogue," even his impatience, gave a peculiar charm to the impression he produced; but you did well to have been behind the scenes if you wished to gather the full meaning of his message. His demonstrations were unique in character; few realize the infinite, loving care he devoted to their preparation. In their simplicity they were often profound. I can never forget the impression I received when I first saw him burn diamond under liquid air—the gradual accretion of the carbon dioxide snow-shower and the blueing of the fluid by ozone, also demonstrated by the iodine test; then the rapid uprush of the mercury in a barometer-tube full of air when the tube was cooled with liquid hydrogen; it all but knocked the top off; or again, the production of ozone at the surface of solid oxygen by the impact of ultra-violet radiations. At such moments—and there were many such—the heart beat with joy at the significance of his feats of inspiration.

[3] Nature **111**, 472 (1923).

Meetings of Association Chapters

WESTERN PENNSYLVANIA AND ENVIRONS

FIFTY-FOUR members were present at the annual fall meeting of the Association of Physics Teachers of Western Pennsylvania and Environs, held at the Carnegie Institute of Technology on November 9, 1940. Seven papers were presented.

COLORADO-WYOMING

THE Colorado-Wyoming Chapter of the American Association of Physics Teachers held its annual meeting at Laramie, Wyoming on October 18, 1940, in conjunction with the Physics Section of the Colorado-Wyoming Academy of Science. The following officers were elected for 1941: Louis R. Weber, Colorado State College, *President;* Malcolm C. Hylan, University of Colorado, *Secretary-Treasurer.* W. B. Pietenpol, University of Colorado, represents the chapter on the executive committee of the Association.

CHICAGO

The annual meeting of the Chicago Association of Physics Teachers was held at Lake Forest College on October 20, 1940. The president of the chapter, Roscoe E. Harris, presided. Nineteen members were present. The meeting was devoted to an informal discussion of what physics departments of colleges and universities might do to aid in national defense. It seemed to be the consensus of opinion that institutions should not offer special defense courses unless requested to do so by military or naval authorities. After the meeting Professor and Mrs. Harris entertained the members and their wives at a tea.

Officers were elected for 1941 as follows: Glenn W. Warner, Wilson Junior College, *President;* Walter E. Peterson, Herzl Junior College, *Vice President;* M. Alden Countryman, Lewis Institute, *Secretary.* The President represents the chapter on the executive committee of the American Association of Physics Teachers.

Performance of the Physical Science Candidates in the National Teacher Examinations

CHARLOTTE W. CROON
Cooperative Test Service of the American Council on Education, New York, New York

THE preparation of secondary school teachers has been the subject of a number of studies, some concerned with the professional equipment considered desirable, others dealing with the training available to, or required of, prospective teachers. However, little information has been presented about the characteristics of teaching candidates based on objective measures of the quality of the candidate's general educational background and the extent of his knowledge of his subject rather than the number of semester-hours of courses taken.

Information of this type is now available with respect to the group of teaching candidates, including a number of candidates for positions teaching physical sciences, who participated in the 1940 National Teacher Examination program.[1] This program was made available to school administrators by the National Committee on Teacher Examinations of the American Council on Education. The examinations were administered on March 29–30, 1940, in 23 examining centers. The purpose of the program—the first of an annual series[2]—is to provide a teacher-examination service for the use of school administrators charged with the selection of teachers.

The battery of examinations was planned to provide valid and reliable measures of those phases of a candidate's fitness that can be adequately appraised by objective tests, such as intellectual capacity, ability to understand and express ideas, general cultural knowledge, knowledge of current social problems, professional educational knowledge and special competence in a teaching field. No attempt was made to include any measure of personality or character in this first battery; the local authorities made their own provision for rating these factors as well as for evaluating training and experience. Each school system participating also made its own decision as to the relative weights to be given these objective examinations and the interviews, practical demonstrations and other evaluation technics available to them.

The following tests, designed to cover the general educational and cultural background of the prospective teachers, were taken by all candidates: Reasoning (nonverbal); English comprehension; English expression; general culture, consisting of sections on current social problems, history and social studies, literature, science, fine arts, and mathematics; professional information; and contemporary affairs.

In addition, candidates for secondary school positions were expected to take special subject-matter examinations, each 90 min in length, in any two of the following fields: English, social studies, mathematics, biological sciences, physical sciences, French, German, Spanish, Latin. A single special examination, 120 min in length, was taken by most elementary school candidates.

Of the more than 3700 candidates who participated in the program, 342 took the examination in physical sciences as one of their subject-matter examinations. Ninety-eight selected it as their first teaching preference, and 244 as their second. Since all scores are reported in *Scaled Score* units,[3] it is possible to make direct comparisons of the scores of the total group of physical science candidates with those made by the other special subject-matter groups. Table I gives the median Scaled Score of each of these subject-matter groups on the different tests of the common battery.

[1] For a discussion of the origin, general purpose and plan, administration and general results of these examinations, see David G. Ryans, Sch. and Soc. **1345**, 273–284 (1940), and John C. Flanagan, J. Exp. Ed., March, 1941. Preprints are available from the National Committee on Teacher Examinations, 15 Amsterdam Ave., New York, N. Y.

[2] The 1941 examinations will be given on March 14–15. For information, communicate with the National Committee, reference 1.

[3] The raw scores were converted so that a score on one test would be similar in meaning to a corresponding score on another test. A Scaled Score may be regarded as a score that has been adjusted to a common scale having a range of approximately 100 points on which a score of 50 represents an average value for these *achievement tests* similar in meaning to the IQ of 100 for intelligence tests (the average of an unselected group of individuals taking an intelligence test).

TABLE I. *Median Scaled Scores of the subject-matter groups on the common tests.*

GROUP	NO. OF CANDIDATES	REASONING	ENGLISH COMPREHENSION	ENGLISH EXPRESSION	GENERAL CULTURE						PROFESSIONAL INFORMATION	CONTEMPORARY AFFAIRS
					CURRENT SOCIAL PROBLEMS	HISTORY	LITERATURE	SCIENCE	FINE ARTS	MATHEMATICS		
Elementary school	579	57	59	60	56	56	59	56	61	57	59	56
English	1126	59	69	67	65	66	71	60	67	61	64	65
Social studies	1090	59	66	62	67	69	66	60	64	61	64	67
Mathematics	463	71	64	61	64	63	61	68	61	79	66	65
Biological sciences	351	62	65	59	64	63	61	72	61	66	63	64
Physical sciences	**342**	**66**	**66**	**60**	**66**	**64**	**60**	**77**	**61**	**76**	**66**	**68**
French	270	60	69	71	63	63	71	57	68	62	64	63
German	74	60	70	69	64	65	67	61	67	64	61	64
Spanish	67	59	68	64	60	66	67	56	64	59	62	63
Latin	148	60	72	74	64	64	72	59	65	65	66	63
Total group	3726*	60	64	61	62	62	63	60	63	61	63	63

* This figure includes a number of candidates who took only the common examinations.

As would be expected, the physical science group does particularly well on the reasoning test and on the science and mathematics sections of the general culture test. On the contemporary affairs test, their median score is higher than that of any other group. Their median score is also above the median for the total group in English comprehension, current social problems, history and professional information. It is not surprising that their median score should be slightly below the general median in literature and fine arts, and their relatively low score of 60 on English expression lends some credence to the often heard assertion that people trained in the scientific fields tend to lack the ability to express themselves well. On the whole, however, their performance is very good. It is interesting to notice that their pattern of achievement is quite similar to that of the mathematics candidates. There may be considerable overlapping between these two groups since probably many of those who chose physical sciences as one option chose mathematics as the other.

While these comparisons show that, as a group, the prospective teachers of physical sciences are relatively high in general ability and background knowledge, a study of the distribution of scores reveals that the range of ability represented in the group is exceedingly wide. In English expression, for example, the range in Scaled Score is from 24 to 91, and in reasoning from 26 to 100. As will be seen later, this wide range in knowledge is equally pronounced in the special subject-matter examination in physical sciences.

As an introduction to a discussion of the results on the examination in physical sciences, it may be of interest to give some information about its content and construction. It was designed to measure the subject-matter competence of prospective teachers of physics, chemistry, and general science.[4] The time limit was 90 min, and 119 questions were included. Dr. Richard E. Watson, the Science Editor of the Cooperative Test Service, assumed immediate responsibility for the test. He was assisted by a subject-matter expert in each of the several fields of physical science covered. The first step was to draw up a tentative outline of the objectives of the test and the subject matter to be included. This outline was based on an analysis of textbooks, college catalogs and courses of study, and was submitted for criticism to a large number of subject-matter experts and teachers of methods of teaching physical sciences and to many city school supervisors and teachers in the field. The outline was revised on the basis of their suggestions, and test items were written covering the points to be included. These items were tried out in experimental form in order to determine their difficulty and ability to discriminate between good and poor students. A tentative final form was then constructed, the items being selected in such a way as to insure appropriate difficulty, high discrimination and adequate coverage of the points in the outline. This tentative form of the test itself was examined by the same critics and the final form prepared for printing. The final allotment of subject matter was approximately as follows: physics, 40 percent; chemistry, 40 percent; earth science, 16 percent; astronomy, 4 percent. A few items on teaching methods in science were included.

The items were all of the five-choice objective type, and

[4] While the test emphasized aspects of physics and chemistry covered in general college courses and essential for science teaching at the secondary school level, it also included relevant topics in the more advanced phases of these subjects.

the raw scores on the test were computed by subtracting one-fourth of the number of wrong responses from the number of correct responses (this subtraction is made to correct for guessing). A few sample items are given below together with the figures indicating the percent of candidates choosing each response. These candidates are divided into two groups, the high group (labeled *H*), consisting of those whose scores were in the upper quarter of the entire group, and the low group (labeled *L*), consisting of those whose scores were in the lower quarter.

1. Ten 60-watt lamps and one 900-watt flatiron are to be used in an ordinary house circuit supplied with 110 volts. After they are all turned on and are heated up, the total current which they carry is about

H	*L*	
8%	*8%*	(1) 8 amp.
5%	*12%*	(2) 10 amp.
1%	*9%*	(3) 12 amp.
77%	*31%*	(4) **14 amp.**
0%	*6%*	(5) 20 amp.
9%	*34%*	*Item omitted*
0%	*0%*	*Item not reached*

2. The sky appears to be blue because the light of high frequency, as compared with the light of low frequency, undergoes

H	*L*	
22%	*17%*	(1) negligible absorption.
3%	*5%*	(2) less energy loss.
10%	*10%*	(3) better transmission.
1%	*23%*	(4) less polarization.
56%	*24%*	(5) **more scattering.**
8%	*17%*	*Item omitted*
0%	*4%*	*Item not reached*

3. If CCl_4 were boiled in a dish over an alcohol flame in the absence of drafts, the CCl_4 vapor would probably

H	*L*	
1%	*8%*	(1) ignite and explode.
2%	*17%*	(2) react with unburnt alcohol vapor to produce chloroform.
63%	*9%*	(3) **displace the air from around the dish.**
10%	*7%*	(4) spread an acrid smell throughout the room.
2%	*5%*	(5) form a fog near the ceiling of the room.
12%	*23%*	*Item omitted*
10%	*31%*	*Item not reached*

4. Which one of the following experiments in elementary physics should probably be a teacher demonstration rather than an individual laboratory experiment?

H	*L*	
2%	*4%*	(1) the equilibrium of three forces.
1%	*6%*	(2) the heat of fusion of ice.
2%	*8%*	(3) the refractive index of plate glass.
1%	*7%*	(4) voltaic cells and Ohm's law.
92%	*70%*	(5) **the heat of combustion of illuminating gas.**
1%	*3%*	*Item omitted*
0%	*2%*	*Item not reached*

5. Winds are produced chiefly by the

H	*L*	
93%	*77%*	(1) **uneven heating of large air masses.**
5%	*12%*	(2) centrifugal forces caused by the earth's rotation.
0%	*2%*	(3) ionization of the upper atmosphere.
0%	*2%*	(4) precipitation of vapor as rainfall.
0%	*0%*	(5) pressure of the sun's radiation.
1%	*1%*	*Item omitted*
1%	*6%*	*Item not reached*

Table II gives the complete distribution of the scores of the physical science candidates on their special subject-matter test in terms of Scaled Scores and raw scores. The range in raw score is from 0 to 88, out of a possible 119. Seven of the 342 candidates made raw scores of 0 or 1, and 25 percent of 14 or less. On the whole, the scores are fairly low. One probable reason for this is that many of the candidates were prepared in physics *or* in chemistry, but not in both, in con-

TABLE II. *Distribution of scores on the subject-matter test in physical sciences.*

	Scaled Score	Raw Score*	Frequency
	94–95	83–88	3
	92–93	78–82	1
	90–91	73–77	3
	88–89	68–72	2
	86–87	64–67	5
95%ile = 84	84–85	60–63	6
	82–83	56–59	9
	80–81	52–55	13
	78–79	48–51	13
	76–77	44–47	20
75%ile = 74	74–75	41–43	21
	72–73	38–40	17
	70–71	34–37	14
	68–69	31–33	14
	66–67	27–30	24
50%ile = 65	64–65	25–26	16
	62–63	22–24	24
	60–61	19–21	22
	58–59	17–18	13
25%ile = 56	56–57	14–16	25
	54–55	12–13	17
	52–53	10–11	20
	50–51	7–9	16
5%ile = 48	48–49	5–6	11
	46–47	4	1
	44–45	2–3	5
	42–43	0–1	7
	Number,	342	
	Median,	26	
	Mean,	29	
	Standard deviation,	18	

* Maximum possible raw score, 119.

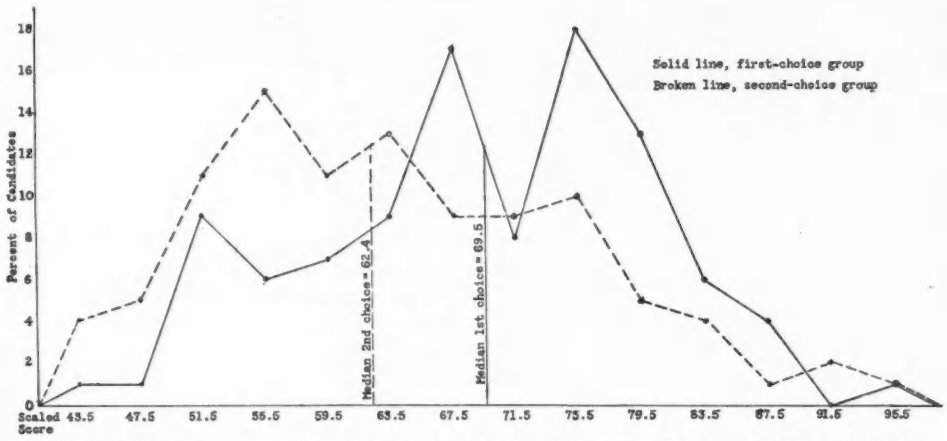


FIG. 1. Distribution of scores on the examination in physical sciences of candidates selecting physical sciences as first choice and as second choice.

trast to the situation in such subjects as mathematics or French where the content is more homogeneous and the candidates have more nearly the same preparation. With increasing emphasis on subject-matter integration and lowering of the barriers between the various scientific fields, this condition may gradually change.

The test provided ample opportunity for the better candidates to demonstrate their superiority, and, since the administrators who use the results are ordinarily more interested in those whose scores are above the median, it appears to be a satisfactory measuring instrument for its purpose.

In connection with this question of range of score, it is interesting to compare the performance of those who gave physical sciences as their first teaching preference with the performance of those who gave it as second choice (Table III). Less than half as many people selected physical sciences for their first choice as selected it for their second. There is not much difference between the two groups on the common examinations, except in the case of the reasoning test, where the second-choice group is definitely better. The general pattern of the second-choice group is more similar to that of the mathematics group, and, as stated before, it is likely that many of the people who took physical sciences as their second choice took mathematics as their first.

Figure 1 shows a large amount of overlapping between the two groups in their scores on the special subject-matter examination in the physical sciences. While it is true that the median of the first-choice group is seven Scaled Score points above that of the second-choice group, the range of score is the same for the two groups.

SUMMARY

The performance of the physical science candidates on the 1940 National Teacher Examinations may be characterized as follows:

TABLE III. *Median Scaled Scores on the common examinations for candidates selecting physical sciences as first teaching preference and second teaching preference.*

					General Culture							
	No.	Reasoning	English Comprehension	English Expression	Current Social Problems	History	Literature	Science	Fine Arts	Mathematics	Professional Information	Contemporary Affairs
First choice	98	62	67	60	66	63	60	79	61	74	65	68
Second choice	244	67	65	60	66	65	60	76	60	77	67	68

1. On the whole, the physical science candidates are relatively high in general ability and background knowledge.

2. The group does particularly well on the reasoning test, the science and mathematics sections of the general culture test, and the contemporary affairs test.

3. The median for the group is slightly below the median for the entire group in English expression, literature and fine arts.

4. The range of general ability and of subject-matter knowledge among the physical science candidates is wide.

5. The overlapping between the first-choice group and the second-choice group in subject-matter knowledge is great.

6. The general pattern of the physical science group is similar to that of the mathematics group.

The 1940 National Teacher Examination in Physical Sciences thus appears to serve as a useful measuring instrument in discriminating among candidates in the upper half of the group. The administrator who has available the distribution of scores on this test has a means of selecting teachers of demonstrated competence in their subject-matter field.

The New England Section of the American Physical Society

THE sixteenth regular meeting of the New England Section of the American Physical Society was held at Phillips Exeter Academy on October 19, 1940. The invited papers were as follows:

Symposium on Problems in the Logic of Physics—

The Observer as Part of an Experimental System. Rogers D. Rusk, *Mount Holyoke College;*

Does Philosophy Help Us Understand Physics? Philipp Frank, *Harvard University;*

What Do We Mean by an Explanation in Physics? R. B. Lindsay, *Brown University;*

Phrasing of the Principle of Indefiniteness. K. K. Darrow, *Bell Telephone Laboratories.*

The Secondary School and Physics in General Education. A. Longacre, *Phillips Exeter Academy.*

Photography in the Physics Curriculum. Carl W. Miller, *Brown University.*

Electrostatic X-Ray Generators for Medical Use. J. G. Trump, *Massachusetts Institute of Technology.*

Five ten-minute papers were contributed. The abstract of one of these is given below. Abstracts of the other four appear in *The Physical Review.*

Model Showing Variable Astigmatism—a Modification of Gardner's Model. ERIC ROGERS, *Mount Holyoke College.*—In this model the amount of astigmatism can be varied by varying the ellipse. The holes from which the "rays" start are drilled, evenly spaced around a circle, in a metal plate—as in the Gardner model—but the holes on the ellipse at the other end are drilled in two sets of parallel brass bars arranged in a parallelogram linkage like a pantograph. These holes are drilled so that when the two sets of bars are at right angles the holes are evenly spaced around a circle; then, by pulling one pair of diagonally opposite corners of the linkage outward (making the other pair move inward), we can distort the circle, with uniform linear distortions, into an ellipse. With the bars arranged for a circle we have a pencil of "rays" crossing through a "point image"; but when the linkage corners are pulled out the pencil becomes increasingly astigmatic. The linkage is supported in a framework at its end which keeps its center fixed but allows one pair of corners to slide out or in horizontally, and the other in or out vertically. Thus, when arranged for a circle, both sets of bars make 45° with the horizontal. To enable the "rays" to stretch, they are made of Lastex sewing machine thread. After a year's use the thread slackens, but re-threading is easy if it is done systematically. For elementary teaching it is helpful to have another, fixed framework with "rays" diverging from an object-point. When the two frameworks are placed end to end, the junction between them represents a lens.

The officers for 1941 are: F. H. Crawford, *Chairman;* P. M. Morse, *Vice Chairman;* J. C. Boyce, *Secretary-Treasurer;* H. E. Farnsworth and J. H. Van Vleck, *Program Committee.* The next meeting of the Section will be held in October, 1941, at Smith College.

NOTES AND DISCUSSION

Cleaning Resistance Box Plugs

IT is desirable, as a matter of routine, to clean resistance box plugs two or three times each year. This may be done rapidly and well by chucking them in a drill press and polishing them with silver polish on a cloth. After all dirt and corrosion have been removed, a clean, dry cloth may be used to remove the polish.

JOHN HARTY

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Cape Girardeau, Missouri.

Nonconservation of Energy—A Paradox

THE following paradox aroused such widespread and spirited discussion in one of the writer's classes in freshman physics that he feels it may be of interest and use to other teachers.

A long piece of thin ribbon is wound up into a solid roll. It is assumed that the ribbon is perfectly flexible and noncohesive, but not frictionless. The outside of the outer end of the ribbon is tacked or glued to the upper end of a smooth inclined plane. The plane is at least as long as the ribbon. Air resistance is made negligible by putting the entire system in vacuum, and then the roll of ribbon is released and allowed to unwind down the plane. The gravitational potential energy of the unwound ribbon is evidently less than half of the initial potential energy. What has become of the difference between the two potential energies?

LEONARD T. POCKMAN

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Physics for General Education

THE decrease in interest and enrolment in high school physics courses during the past few years is of considerable importance to everyone associated with the physical sciences. With this in mind, the Central Association of Science and Mathematics Teachers appointed a committee with one of us as chairman to investigate the possibilities of making improvements. Scholarships provided by the General Education Board made it possible to invite five active high school physics teachers from different parts of the country to serve on the committee. Professor R. W. Tyler then made available the facilities of the University of Chicago Workshop in General Education for a five-week period.

After some preliminary discussion, it was agreed to focus attention on a course of study for the majority of high school students. The objectives for such a course are: to give the student an understanding and appreciation of those fundamental concepts which are the foundation of the science of physics; to enrich the student's understanding of, and appreciation for, these concepts by numerous applications from his everyday life and from industry; to present the subject matter to the student in such a manner that it will establish habits of reflective thinking and promote the use of the scientific method in solving everyday problems; and to show clearly to the student the method which science uses to obtain knowledge.

An attempt was made to analyze the difficulties of a high school physics course and the following conclusions were reached: the concepts themselves are difficult; analysis is a difficult process; the vocabulary used is new and extensive; the mathematical formulation of the concepts and the symbols used are new; the units in these mathematical formulations are numerous and confusing.

It appears that, for a general education, a thorough understanding of a limited number of the basic concepts of physics is of more importance than exact numerical answers to many individual and seemingly unrelated problems. Hence, it was proposed to center attention on fewer concepts and required new words than are included in the orthodox course; to place strong emphasis on the use of these concepts in everyday physical situations, and to use mathematical symbolism and numerical results only when these give definite advantages.

To facilitate progress, the problem was divided into three parts, and two or more members of the group were assigned to each part. The parts consisted of an outline of the subject matter topics to be included, the assembly of lists of all types of aids for the teacher, and the preparation of questions, problems, and test exercises designed to promote realization of the aims of the course.

It is our belief that students who take this course and then decide to continue physics in college will have acquired a mastery of the fundamental principles sufficient to insure success in their college work. Such a course as this may be easily extended to include more mathematical analysis for the superior students.

R. J. STEPHENSON

University of Chicago,
Chicago, Illinois.

GLEN W. WARNER

Wilson Junior College,
Chicago, Illinois.

A Mechanical Switching Arrangement for Oscillograph Demonstrations of Certain Electric Transients

IN order to have stationary curves on an oscillograph representing certain electric transients, such as the charging and discharging of a condenser through an inductive circuit, it is necessary to have a switching arrangement which will give the desired connections at equally repeated intervals of time. Thyratron switching[1] has been used for this purpose. However, in some demonstration and student laboratory work, mechanical switching seems more desirable than thyratron switching, as only those electric circuits whose properties one is interested in determining are involved.

The mechanical switching arrangement described in this

paper is a rotating commutator, shown in Fig. 1. Segments A, E, H and K were made of monel metal $\frac{1}{32}$ in. thick and glued with metallic glue to an ebonite disk $\frac{1}{4}$ in. thick and $4\frac{1}{4}$ in. in diameter. The radial width of the segments was $\frac{3}{4}$ in. with $\frac{1}{32}$ in. spaces between the segments. Segments E, and H serve as insulators for commutation which allow the brushes to ride on monel surface at all times. The three brushes shown in Fig. 1(a), with a side view in Fig. 1(b), were each made of a piece of multiple-strand (strands No. 36 B & S gauge) copper wire $\frac{3}{16}$ in. in diameter and 1 in. long fastened to one end of a strip of hard copper $4\frac{1}{2}\times\frac{3}{4}\times\frac{1}{32}$ in. The other end of each copper strip was fastened to a piece of ebonite (not shown) with an electric connection on each.

The commutator was rotated at a speed of about 30 rev/sec by means of a Cenco variable speed rotator. The other equipment used in the following demonstration were: a Dumont cathode-ray oscillograph with a 5-in. tube; a 1 μf condenser, subdivided; a dial resistance box, 1 to 9999 ohms; a 100-mh self-inductance; a reversing switch; and a 6-v storage battery.

The circuit in Fig. 1 is that used for showing the curves representing the charging and discharging of the condenser C through the self-inductance L and the resistance R. When the switch S is in position *2*, the commutator connects brushes N and P, charging C through L and R, and then connects brushes M and N, discharging C through L and R. The potential drop across L and R, which is the same as that across C, is applied to the vertically deflecting plates of the oscillograph. With this circuit the series of oscillograms in Fig. 2, with all variations between, can be obtained by changing the value of the resistance.

When the switch S is in position *1*, the condenser is charged without L and R in the circuit and then it is discharged through L and R as before. This gives the discharge curves alone, which are the right-hand halves of the oscillograms in Fig. 2. This enables one to distinguish between the charge and discharge parts of the curves as shown in Fig. 2.

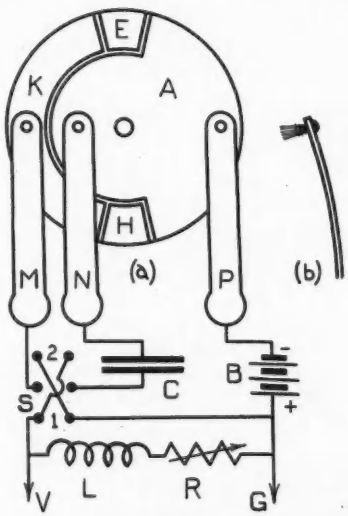
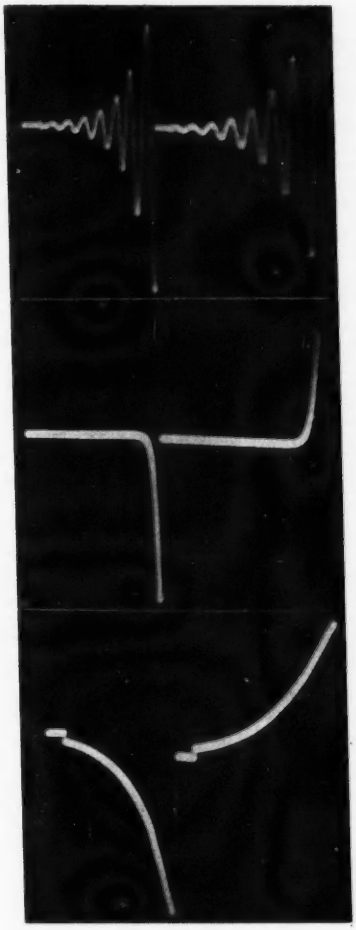


FIG. 1. (a) Commutator design and wiring diagram; (b) Side view of brushes M, N and P.



(a) $R=66$ ohms.

(b) $R=632$ ohms.

(c) $R=10^4$ ohms.

FIG. 2. Oscillograms of condenser charge and discharge through an inductive circuit. (The time sweep is from right to left.) C, 1 μf; L, 100 mh.

The effect of changing the capacitance or inductance can be shown by making the desired changes in C and L.

The oscillograms on this tube could be seen adequately for demonstration purposes at a distance of about 50 ft.

The demonstration can be made into a very good student laboratory experiment for studying the properties of condenser charge and discharge.

L. E. SMITH, JR.*

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[1] Trotter, Am. J. Phys. (Am. Phys. T.) 7, 411 (1939); Green, Am. J. Phys. (Am. Phys. T.) 5, 181 (1937).

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A Subject Matter Inventory

IT is proposed that an inventory of the subject matter discussed in elementary textbooks on general physics be taken with a view toward discarding outmoded stock which may have accumulated on the shelves and replacing it with recent and current stock.

Physicists are proud of the contributions of their science to the developments of our civilization. This pride has caused the textbook author and the teacher not only to cling to the story of the discovery and the analysis of fundamental phenomena but to use both textbook space and teaching time to describe in detail engineering devices which have resulted from the application of these fundamental principles. This amounts to an admission that it is not the principles and the experiments but the engineering devices that are interesting to the student. I would advocate not the omission of brief statements mentioning the application of a principle to a machine, but the omission of involved descriptions of such devices and, especially, the meaningless photographs that accompany such descriptions. All of us can recall general physics textbooks of the last 10 years that contain obscure photographs and superficial discussions of drum and ring armatures of large motors and generators, rotary converters with the appended: "Courtesy of this or that Electric Company," synchronous and induction motor rotors, large transformers hidden in huge steel cases, multiplex and duplex telegraph systems, hand-set telephones, traveling overhead cranes, iconoscopes, thyratron and ignatron tubes, *y*- and Δ-connections of transformers, water-cooled tubes for 50,000-w radio stations (pictured as opaque cylinders), enclosed Diesel engines, large power-plant installations, the mechanism of a steam engine governor, large encased steam turbines, modern household refrigerators, etc. Although such pictures and discussions are particularly common in books purported to be written for engineering physics students, I can see a greater justification for their inclusion in a textbook written for students in arts and sciences. In recent years I have been reproached by teachers of engineering subjects who asked why the teacher of elementary physics cannot "stick" to his physics instead of "taking the cream off" their subject before the student reaches them.

Recently I made a survey of the subject matter of a popular physics textbook and, with my criterion, found that the volume, already too long, could be reduced approximately 100 pages by omitting the general engineering discussions and, at the same time, mentioning various principles used in practical devices. Most teachers find textbooks of physics too voluminous for the time assigned, and this discovery is not of recent origin. For example, Deschanel's *Elementary Treatise on Natural Philosophy*, published in 1873, has 1050 pages, 760 engravings on wood and 3 colored plates; and, while most of the subjects which I have here suggested for omission are not included, there are engravings and discussions of such topics as Foucault's regulator for arc lamps, Fromont's rotary magnetic engine, Morse's telegraph with relay, Papin's digestor, Watt's engine, Gifford's injector, a section of a locomotive, various magnetoelectric machines and fire engines. Doubtless many teachers do not assign the engineering topics appearing in the textbooks, but I have found that such a procedure is misinterpreted by the student.

In place of the engineering topics, I would propose a more complete discussion of contemporary physics. The present-day student of elementary physics is intensely interested in recent contributions, this having been brought about in part by the prompt newspaper publicity given to scientific discoveries. The average engineering student in physics today is far more interested in fission than in a discussion of a steam engine governor. It does not add to the enthusiasm of the student for the author to state in the preface of his textbook that only physics preceding the twentieth century is to be discussed.

In conclusion, I ask: Should we not discard those subjects that have gradually passed over to the field of engineering, put added emphasis on the principles of fundamental physics and bring the subject matter more in phase with contemporary physics?

G. E. GRANTHAM

Cornell University,
Ithaca, New York.

Charles Jules Cosandey, 1894–1940

CHARLES Jules Cosandey, of the Duluth Junior College, died at the hospital in Little Falls, Minnesota, on June 26, 1940, from burns after contacting a 6600-v circuit at the Blanchard Rapids dam, where he was spending the summer on a survey and inventory for the Minnesota Power and Light Company.

Mr. Cosandey was born in Lucens, Vand, Switzerland, on October 31, 1894. He received his early education in the schools of North Dakota and attended the University of Minnesota, where he received the Degree of Bachelor of Science in Electrical Engineering in 1925. His graduate work was done at Iowa State College, where he received the M.S. degree in electrical engineering and physics in 1926, and at the University of Minnesota. In 1918–19 he served with the United States Army in France. He was a member of the American Association of Physics Teachers, the American Institute of Electrical Engineering, the American Institute of Radio Engineering, the American Association for the Advancement of Science and the Minnesota Academy of Science.

While at Iowa State College, Mr. Cosandey served as a graduate assistant. In 1926–27 he was instructor in electrical engineering and physics at the University of South Dakota. Coming to the Duluth Junior College in 1928, a year after it opened, he served efficiently until the time of his death as instructor in physics, electrical engineering and mathematics. In recent years he became interested and trained in student testing, and served with distinction as chairman of the faculty committee on personnel and guidance.

R. D. CHADWICK

Available Graduate Appointments and Facilities for Advanced Study (Continued)

Before attempting to make use of this information, the reader should consult the foreword to the list of 91 institutions that appeared in the December, 1940, issue.

Note—Unless otherwise specified, the application must be filed with the person designated *before March 1;* if no person is designated, address the head of the Department of Physics. "M only" means that the master's degree is the highest degree granted. "No form" means that a special application form is neither furnished nor required. The numerals preceding the parentheses indicate the probable number of vacancies for next year; those in parentheses indicate the total number of appointments existing in the department; e.g., 2(3) *fellows* means that three fellowships exist, two of which probably will be vacant and open to competition in 1941–1942. Except where otherwise indicated, appointees do not have to pay tuition (t.) or fees (f.). Under *R* are listed fields of research that are stressed in the department and under *U*, unusual facilities for research and study.

Bryn Mawr College, Dean Eunice M. Schenck, Bryn Mawr, Pa. 1(2) *half-time demonstrators*, lab. teach. and asst., $750; 1(1) *fellow*, 3 hr/wk service, $860 less $320 t. and f.; 1(1) *scholar*, no service, $400 less $320 t. and f. *R:* properties of metals. particularly surface properties; x-ray crystal structure; biophysics.

Fordham University, Graduate Dean, New York, N. Y. Apr. 1, 1(3) *graduate assistants*, lab. asst., $600 less $100–150 t. and f. *R:* geophysics; seismology; cosmic rays. *U:* seismic observatory.

Georgia School of Technology, Prof. J. H. Howey, Atlanta, Ga. M only. 1(2) *graduate assistants*, lab. asst. and grading, $600.

Illinois Institute of Technology (A consolidation of Armour Inst. of Tech. and Lewis Inst.), Dean L. E. Grinter, 3300 Federal St., Chicago, Ill. Apply by Feb. 20 if possible. Various academic and industrial scholarships, fellowships and assistantships, $300 to $1000, less $150–300 t.

John Hopkins University, Prof. G. H. Dieke, Baltimore, Md. In addition to the three types of appointments described in the December, 1940, issue, 3 new *scholarships*, $1000 less $300 t., are available; if the holder shows promise this type of scholarship may be renewed twice and may be followed by a 1-yr appointment as *instructor*.

Kansas State College, Prof. A. B. Cardwell, Manhattan, Kan. M only; Apr. 1; no form. ?(2) *graduate assistants*, lab. teach., $500 less $50 t. and f. *R:* applied spectroscopy; x-rays; electron emission.

Lehigh University, Prof. C. C. Bidwell, Bethlehem, Pa. 2(6) *graduate assistants*, 15 hr/wk lab. asst., $600. *R:* spectroscopy; x-rays; electron emission; nuclear physics; properties of metals; magnetic properties of crystals.

Missouri School of Mines, Rolla, Mo. M only. No graduate appointments available at the present time.

Oberlin College, Dean E. F. Wittke, Oberlin, O. M only; Mar. 15 1(1) *graduate scholar*, $300. *R:* soft and hard x-rays; certain fields of thermionics; spectroscopy. *U:* soft x-rays.

Purdue University, Prof. K. Lark-Horovitz, Lafayette, Ind. May 15. 4 *half-time assistants*, 6 hr/wk teach.; 1 *instructor*, 9 hr/wk teach., candidate must have Ph.D., $1500. *R* and *U:* x-rays; electron diffraction; spectroscopy; acoustics; gas discharge; cyclotron, Van de Graaff generator, etc., for nuclear physics.

Radcliffe College, Graduate Dean, Cambridge, Mass. Various fellowships and grants-in aid, $450 to $1200 less $450 t. The graduate course work and research are carried on in Harvard University.

St. Louis University, Dean Thurber M. Smith, St. Louis, Mo. Mar. 15. 2(2) *graduate fellows*, $300 to $540. *R:* photoelectricity; photography; positive ions.

The Institute of Paper Chemistry (affiliated with Lawrence College), Dean, Appleton, Wis. Mar. 15. 10–15 *scholars*, increasing from $650 to $925 during 4-yr course. The applicant's undergraduate preparations must include, besides physics, 4 yrs chem., 2 yrs math. and a reading knowledge of German. *R:* applied physics. *U:* spectrophotometric, spectroscopic, optical and electrical instruments and equipment.

University of Alabama, University, Ala. M. only. 5 *assistants*. *R:* x-rays; optics; electrical measurements; radioactivity.

University of Arkansas, Prof. L. B. Ham, Fayetteville, Ark. May 1; M only; no form. 2(4) *graduate assistants*, grading, apparatus, $5 to $15/mo. less t. and f. *R:* sound and related problems.

University of Colorado, Boulder, Colo. Apply any time. 1–3 *graduate assistants*, lab. and class asst., $450 to $600 less $94.50 t. and f.; 1 *research fellow*, study and research, $400; 1–2 *university fellows*, study and research, $200; 1–2 *scholars*, study and research, remission of t. and physics f. For assistantships apply to Prof. W. B. Pietenpol; for other appointments, to Graduate Dean.

University of Florida, Gainesville, Fla. M only. 2(3) *graduate assistants*, lab. asst., $450 less $30 f., apply to Prof. R. C. Williamson by Apr. 1; ?(?) *graduate fellows*, $300 less $30 f., apply by Mar. 15 to Graduate Dean. *R:* x-rays; infra-red; Raman effect; dielectrics.

University of Georgia, Athens, Ga. M only. 3 *graduate assistants*.

University of Iowa, Prof. G. W. Stewart, Iowa City, Ia. Several *graduate assistants*, *scholars*, *fellows*, *research assistants* and *research associates*. *R:* spectroscopy; resonance radiation; molecular beams; physical characteristics of single crystals of metals and alloys; nuclear physics (a 500-kv and a 5-Mv plant); x-rays, and x-ray diffraction in liquids; electron excitation.

University of Toronto, Toronto, Can. No form. 9(9) *assistant demonstrators*, 13–14 hr/wk lab. asst., $500 less $75 t. and f. *R:* low temperatures; spectroscopy; geophysics; meteorology; thermionics; x-rays. *U:* liquid hydrogen and helium; hyperfine structure in spectroscopy; electron microscope.

University of Washington, Prof. H. L. Brakel, Seattle, Wash. No form. 6(18) *fellows*, 20 hr/wk service, $540. *R:* nuclear physics; radioactivity; sound; theoretical physics.

Proceedings of the American Association of Physics Teachers

The Philadelphia Meeting, December 27–30, 1940

THE tenth annual meeting of the American Association of Physics Teachers was held at the University of Pennsylvania and at Drexel Institute, Philadelphia, Pennsylvania, on December 27–30, 1940. The presiding officers were R. M. Sutton, President of the Association, and A. G. Worthing, Vice President.

A joint dinner with the American Physical Society and Section B of the American Association for the Advancement of Science was held in the Crystal Ball Room of the Benjamin Franklin Hotel on Friday evening, December 27.

Invited Papers and Reports

Three invited papers were presented during a joint session with Section B and the American Physical Society on Friday afternoon, December 27:

Ions in Gases. John Zeleny, *Yale University*, President of the American Physical Society.

Higher Energies. E. O. Lawrence, *University of California*, Retiring Vice President of Section B.

Applications of Nuclear Physics. Robley D. Evans, *Massachusetts Institute of Technology.*

A session on Saturday afternoon, December 28, was devoted to a report and three papers on physics in relation to biology and medicine:

Report of the Association Committee on Physics in Relation to Medical Education. W. Edward Chamberlain, *Temple University School of Medicine.*

General Results of Biological Studies with Tracer Isotopes. Joseph G. Hamilton, *University of California.*

Production of Neutrons and Radioactive Isotopes. M. S. Livingston, *Massachusetts Institute of Technology.*

The Physical Basis of Nerve Action. D. W. Bronk, *Cornell University Medical College.*

During a joint session with the American Science Teachers Association, on Monday morning, December 30, the following program was heard:

Award of the Oersted Medal to Robert Andrews Millikan. Duane Roller, *Hunter College*, R. M. Sutton, *Haverford College* and Carl D. Anderson, *California Institute of Technology.*

Demonstration Lecture on Television. T. F. Joyce, *RCA-Victor Corporation.*

Contributed Papers, with Abstracts

The sessions on Saturday morning, December 28, and Monday afternoon, December 30, were devoted to the following contributed papers:

1. Harmonic Analysis of Periodic Curves. James A. Duncan, *Consolidated Edison Company of New York, New York, N. Y.*—The determination of the amplitude and phase relations of the harmonics in a periodic function from its graph is a well-known Fourier series problem. In practical cases, such as the determination of the harmonics in an alternating current from the oscillographic record of that current, one may encounter considerable arithmetic. Suppose that one-half cycle of the curve has been divided into $2m$ intervals terminating at points whose abscissas are $0, \pi/m, 2\pi/m$, etc., and that the ordinates of the curve at points corresponding to these abscissa angles have been measured. The Fourier coefficients A and B of the kth harmonic are computed by taking the sum of $2m$ terms each of which is the product of an ordinate and the cosine or sine, respectively, of k times the corresponding abscissa. The bothersome part of the arithmetic comes from the computation of the terms involving $\sin k\pi/m$ and $\cos k\pi/m$ for the many cases in which $k\pi/m$ is greater than $\pi/2$. It is obvious, however, that each sine will be equal to plus or minus the sine or cosine of some other $k\pi/m$ which is less than $\pi/2$ and likewise with each of the cosines. What one needs is a shorthand method of simultaneously selecting the appropriate function and appropriate sign to form each term of each coefficient. The present paper calls attention to and describes a method of doing this which has been employed in the Consolidated Edison Laboratories and which is due to L. Zipperer.[1]

[1] Dinglers Polytech. J. 333, 201 (1918).

2. First Problems on Force. Robert S. Shaw, *College of the City of New York, New York, N. Y.*—The usual problems on the equilibrium of a particle, when not trivial, present great difficulties to students. This appears to be due in part to the fact that such problems are really three problems in one. Two of these problems are essentially mathematical—making a vector figure, and finding some unknown quantity in that figure. Before these problems can even be tackled the student must solve the only purely physical problem, which is to identify all the forces and only those forces that act upon the object under study. Since the mathematical problems themselves require considerable attention from the student, it seems desirable to separate the difficult physical problem and study it alone. There is a need for an introductory set of problems that call merely for the identification of the forces in a physical situation which has been described in an unambiguous way. Not all of the situations described should involve equilibrium; the forces on a pendulum ball, or on a projectile, will have to be identified at some time during the course. A useful exercise is to identify the forces acting on more than one of the objects involved in a given situation. As a background for these problems, there will need to be some study of the commoner types of forces, such as those exerted by strings, by smooth surfaces, by friction; students do not come into physics with an understanding of these situations. One part of this background will be a statement of Newton's third law as a fundamental property of force. It is an enlightening experience to require a student to state on his own responsibility that no more forces remain to be named.

3. An Experiment for the Determination of μ/ϵ. Noel C. Little, *Bowdoin College, Brunswick, Me.*—Using rationalized mks units, one may check the well-known relation, $(\mu\epsilon)^{\frac{1}{2}}=1/c$. The ratio $(\mu/\epsilon)^{\frac{1}{2}}$, however, yields the less familiar value, 377 ohms. A simple experiment of intermediate grade, in which the magnetic repulsion of current-carrying parallel wires is balanced against their electrostatic attraction, gives this value directly. The apparatus

is essentially an electrodynamometer with both fixed and moving systems consisting of similar pairs of suitably spaced parallel wires. The angular deflection is read by means of a mirror, telescope and scale. The electrostatic attraction has its rise in the potential difference resulting from a resistance connected in series and inserted between the moving and fixed systems. For large values of this resistance, the electrostatic forces predominate; for small values, the magnetic. A null deflection yields the value, 377 ohms, which is independent of the voltages and currents used. Alternating current is used to neutralize the effect of the earth's magnetic field. The currents and voltages are such as readily may be obtained from the power mains and are conveniently controlled by a Variac. Analysis of the theory behind the experiment brings out clearly the arbitrary character of electric and magnetic units and dimensions.

4. A Luminous Potentiometer. W. B. Pietenpol, *University of Colorado, Boulder, Colo.*—For the demonstration of the potentiometer principle to large groups a new piece of apparatus has been constructed. It consists of a large number of miniature lamps mounted in series with a control rheostat. With no resistance in series the lamps have normal brilliancy upon the application of 110-v, d.c.; in this form the effect of series and parallel resistances is clearly shown by the variation in brightness of the lamps. With the use of a battery—say a 6-v storage or 45-v radio battery, the principle of the potentiometer is shown. When the emf of the battery is equal to the *RI*-drop of a definite number of lamps, no change in brightness is indicated when contact is made. When the contact point is varied, the change in brightness of the lamps to the right or left of the contact point shows a proper balance to a degree of accuracy sufficient for demonstration purposes. A lecture table galvanometer in series with the battery permits a more accurate adjustment. The use of a commercial d.c. source across the lamps does not disturb the setting when a galvanometer of relatively low sensitivity is used. However, with an increase in galvanometer sensitivity, the line fluctuations may be clearly shown.

5. A Realistic Approach to Elementary Optics. Eric M. Rogers, *Mount Holyoke College, South Hadley, Mass.*—Just as the study of elementary heat is approached through such practical things as thermometers, electric heaters and kettles—and not "logically" through kinetic theory—so can the study of elementary optics be approached with an increased interest and sense of reality by starting with lenses, images and optical instruments—instead of building with geometry on the laws of reflection and refraction and thus crowding instruments into a later stage. Instruments are the student's real contacts with optics in ordinary life and, with the image-forming properties of lenses demonstrated experimentally, he can study cameras, eyes, magnifying glasses and telescopes in the first two weeks and proceed to microscopes, spectacles and lanterns before he even meets the laws of reflection and refraction. The image-point is defined as "that point to which rays from the object-point are made to converge, or from which they appear to diverge"; and the student finds *experimentally* that lenses form such images. The longitudinal relationship is demonstrated and checked in the laboratory. Instruments are studied with crude models made with simple lenses, and with ray models using a simple *individual* Hartl optical disk set, and they are illustrated by ray diagrams. Then the laws of reflection and refraction are demonstrated—and reflection and refraction at plane boundaries give further examples of virtual images. Throughout, waves may be substituted for rays, or both may be used. Other topics, such as dispersion, spectra, color, photometry and the wave properties of light, are as important as ever, but their places are not affected or defined by the suggested change of order and emphasis. The student will emerge familiar with all the usual topics; but, though he will regard the laws of reflection and refraction as basic laws from which the image-forming properties of lenses and mirrors can be deduced, he is likely to continue to regard images as the main landmarks of optical behavior. An outline was given of a course which has been developed along these lines and tried with a number of classes. Demonstration and laboratory experiments were exhibited.

6. Individual Apparatus for Elementary Optics. Eric M. Rogers, *Mount Holyoke College, South Hadley, Mass.*—Sets of the Hartl optical disk for individual use are easily made if suitable cylindrical lenses can be obtained, and they can be used for a much wider variety of demonstrations than seems customary at present. The set may include a 6- or 10-v lamp with a vertical *line* filament as source, slits for single rays and 3 rays, a painter's "graining-comb" to make fans of rays, a drawing board covered with white paper, and the following lenses, each about 2 in. wide and 1 in. or more high: *plano-cylindrical*, +17 diop, −17 diop (eyepieces, microscope objective, aberrations), +7 diop (telescope objective, compound eyepieces); *bi-cylindrical*, +5 diop, −5 diop (compound lenses, undeviated rays, telescope objective). The following demonstrations are suggested. (1) *Single lens:* undeviated rays; deviation by edge constant; real and virtual images; image distances (move source); magnification (move source laterally); spherical aberration; virtual object (use auxiliary lens). (2) *Instruments:* camera; telescopes (magnifying power, using 2 distant sources, compound eyepieces, erecting systems, Galilean eyepiece, prism inversion); microscope. (In each instrument move source laterally to show magnification.) (3) *Aberrations:* spherical aberration, coma, curvature and distortion can be demonstrated and corrected, one at a time, by grouping lenses and stops; astigmatism can be demonstrated by twisting a lens. (4) *Cylindrical mirror:* image formation with aberrations. (5) *Laws of reflection and refraction:* the angles may be measured to ½° or less with a plane mirror, a rectangular block of good glass, a paper protractor and a radial thread. (6) *Prism and grating:* deviation; dispersion; formation of pure spectrum (with lenses).

7. Two Simple Demonstrations and an Application of Physics in the Home. A. D. Hummel, *Eastern Kentucky State Teachers College, Richmond, Ky.*—(1) *Rotational inertia.* The apparatus, called a "Cum Bac" and retailing for 10 cts., consists of a closed cylinder with a weight held between the ends by a rubber band. When it is rolled the

rubber band is twisted because of the moment of inertia of the weight, and the energy thus stored causes the cylinder to come back. When started down an incline it will stop and roll back up. (2) *Upper auditory threshold.* By squeaking pieces of chalk of different lengths on the blackboard it is easy to show that the pitch rises as the length decreases. When the pitch passes the threshold the auditory distress vanishes. (3) *Vacuum cup application.* A rubber vacuum cup has been found useful for holding a soap tray over the rounded edge of a bath tub.

8. The Electromagnetic Pendulum as an Intermediate Laboratory Experiment. Paul F. Bartunek, *Rensselaer Polytechnic Institute, Troy, N. Y.*—The electromagnetic pendulum described by Calthrop[1] has proved to be an excellent experiment for the advanced undergraduate laboratories in dynamics and electrical measurements, for it correlates the work of the two courses. By means of this experiment the Lagrange equations may be effectively taught to undergraduates. The coils are wound in circular shape and are of such dimensions that the part of the potential energy expression due to the currents is of a relatively simple form. As much as 5 amp may be passed through the coils. Approximations in the differential equation, which result from an application of the Lagrange equations to the system, are made possible by keeping the oscillations very small and applying the theory of small vibrations. The coils are connected in series, and the current may be calculated from a knowledge of their dimensions, their equilibrium distance apart, and the periods with the current off and on. The experiment is repeated with different currents and the computed results are compared with the ammeter readings.

[1] Calthrop, Am. J. Phys. (Am. Phys. T.) **3**, 32 (1935).

9. A Problem Involving the Order of Impacts. Seville Chapman, *University of Kansas, Lawrence, Kans.*—A popular demonstration piece illustrating Newton's third law of motion consists of a row of equal steel balls suspended by bifilar suspensions so as to touch one another. If two or three balls are drawn aside and released, a fascinating motion follows. Assuming perfect elasticity, one explains the motion on the basis of the laws of conservation of energy and of momentum. If one of the end balls has a mass n times the mass of the other balls, then the expressions for conservation of energy and momentum would be satisfied if, after releasing the large ball, n small balls would fly out with a velocity equal to that of the large ball before impact. The actual motion is much more complicated, appearing as a "jumble" of balls, but can be explained on the basis of sequence of impacts. With three balls some very interesting cycles can be produced that depend on the order of impact, which is controlled by the length of the suspensions. The order of impact has been determined oscillographically, the results being in accordance with expectation. The observed time of impact between balls is about 0.00010 sec, depending on the velocity. The maximum observed value of the coefficient of restitution was 99.4 percent.

10. Graphical Representation for Circuit Networks Containing Nonlinear Resistances. P. I. Wold, *Union College, Schenectady, N. Y.*—The difficulties of analytical treatment of even simple circuits containing nonlinear resistance elements are well known. The advantages of graphical methods, in pedagogical as well as practical work, were pointed out. Specific application to unbalanced Wheatstone bridge networks leads to certain conclusions as to the extent of the usefulness of the method in such circuits, as well as its present limitations.

11. A Subject Matter Inventory. G. E. Grantham, *Cornell University, Ithaca, N. Y.*—For the complete paper see "Notes and Discussion" in this issue.

12. Student Likes and Dislikes in the Elementary Laboratory. John S. Rinehart, *Fort Hays Kansas State College, Hays, Kans.*—A study has been made of the opinions of some 150 elementary college physics students regarding their likes and dislikes of 45 different experiments and various kinds of instruction and write-ups. An attempt was made to analyze the experiments in terms of common characteristics, such as quality of results, understandability, complexity of apparatus, practicality, etc. It was found that experiments having no particularly outstanding characteristic were most disliked; while, the presence of any one outstanding characteristic was enough to produce in the student a strong like for an experiment, regardless of the presence or absence of any other. As to subject matter, the best liked experiments were, in order of preference, those in mechanics, heat, electricity and light, and the most disliked, those in mechanics, electricity, light and heat. In general, the results showed that students (1) prefer to be told what to do and exactly how to do it, (2) prefer to perform a few experiments thoroughly and (3) believe that the time spent in the laboratory is not wasted.

13. The Even-Front Laboratory in the General Course. Winthrop R. Wright, *Swarthmore College, Swarthmore, Pa.*—The advantages of the even-front laboratory are: (1) the illustration of principles in the laboratory concurrent with their presentation in lecture; (2) the possibility of general discussion of theory before and during an experiment; (3) the opportunity for quantitative demonstrations in the laboratory; (4) the minor role assumed by the formal report. Offsetting these is the cost of many sets of apparatus, an expense which many feel an insuperable obstacle to any general adoption of the method. To show that inexpensive apparatus may be quite acceptable when due attention is paid to design and operation, details were given for three typical experiments in mechanics: (1) a study of measurement with emphasis on length determination; (2) equilibrium of the nonconcurrent force system in the crane; (3) unaccelerated motion of a block on an inclined plane. The total investment in the 13 experiments for the first semester was about $1100 for handling 20 students in pairs. More than $500 of this was for special pieces which were purchased originally for the advanced laboratories. The problems arising in the more expensive fields of electricity and optics were discussed briefly.

14. Acoustic Filtration. Harold K. Schilling, *Union College, Lincoln, Neb.*—Filterability, which is an interesting, as well as theoretically and practically significant, property of waves, is easy to demonstrate acoustically. A filter according to the design of G. W. Stewart and especially suitable for use in the low frequency range is

already available to teachers commercially. A new type of filter[1] adapted to use with higher frequencies was demonstrated. Attenuation produced by the filter can be shown qualitatively with the usual equipment employed in phonoptics. If, in addition to this, an electric attenuator is introduced into the receiving circuit, the attenuation can be determined quantitatively. Finally, if an electrically driven source is used instead of a whistle, the change of phase produced by the filter can also be demonstrated.

[1] H. K. Schilling, "A lattice type acoustic filter," Phys. Rev. **59**, 111 A (1941).

15. Are Derived Units Derived? Rogers D. Rusk, *Mount Holyoke College, South Hadley, Mass.*—In speaking of certain units as *fundamental* and of others as *derived*, in any given system, there is an apparent implication that often leads to misunderstanding and contradiction. Experience is not arbitrary, while in any purely logical system the choice of fundamental units is arbitrary. The attempt of the physicist to put certain logical patterns of units into correspondence with experience involves a combination of these two elements. Units such as those of mass, length, time, velocity, acceleration and force are symbols having reference both to a logical system of units and to experience. Neither are secondary units derived in the sense of a result contained in the premises, nor can one type of experience be derived from another type. In any secondary unit there is an element of synthesis involving new relations by which the unit is built up, and by which there is obtained in the result a symbol that refers to a unique and different element of experience which is neither secondary nor derived. Hence these terms should be used with proper restraint. Neglect of this and of the fact that priority in any system of units need not mean priority in experience has led to some of the endless discussions of the past.

16. Outlines of Lecture Demonstrations. John A. Eldridge, *State University of Iowa, Iowa City, Iowa.*—Students do not take complete lecture notes; perhaps the organization of the lecture does not encourage note-taking; possibly a sharp mind is more important than a sharp pencil. It is not an arduous task to make mimeographed lecture outlines. These greatly increase the teaching effectiveness of lecture-table demonstrations. Data forms, simple drawings and cartoons, and other teaching devices can be used. If it is understood that outlines are only a general guide, with some experiments omitted, others added, the whole lecture outline revamped when necessary, there need result no excessive standardization of the lectures. Sample outlines were shown.

17. Some Implications of a Recent Study of Secondary School Physics in Pennsylvania. M. H. Trytten, *University of Pittsburgh, Johnstown Center, Johnstown, Pa.*—A tendency seems to exist toward (*a*) declining enrolment in high school physics and (*b*) softening of the course by diminishing laboratory work, giving less mathematics and aiming the course at the noncollege preparatory student. The better class student seems to be the sufferer. The question follows as to who can assist in restoring proper college preparatory training and whether there is any likelihood of the restoration occurring.

18. Hours of Credit Required of Physics Majors in Illinois Colleges and Universities. Lester I. Bockstahler, *Northwestern University, Evanston, Ill.*—The Committee on the Training of Physicists for Industry has reported on a "Suggested four-year curriculum leading to a major in physics;"[1] this report was based on the deliberation of the committee and on the "opinion of some 20 teachers from rather widely scattered institutions." A study has been made of all the institutions in Illinois that offer a major in physics to find how nearly the practice of a diversified group conforms to the suggested program. The study also included a statement of the courses recommended over and above those specifically required by faculty legislation. Taking a weighted mean of the hours reported by all schools, we may summarize the results as follows: (1) the number of hours specifically required in physics, mathematics and chemistry fall about 25 percent below the committee's suggestions; (2) since about 75 percent of the total hours for the graduation requirement is prescribed, the student may, by the proper choice of electives, meet the committee's suggested program; (3) the number of hours recommended (which may be taken as the actual practice) is about 10 percent below the suggested program.

[1] Am. J. Phys. **8**, 124 (1940).

19. Forced Vibration Demonstration Apparatus with Stroboscopic Attachment. J. Lloyd Bohn and Francis H. Nadig, *Temple University, Philadelphia, Pa.*—The apparatus is used to demonstrate forced vibration by applying a sinusoidal force to a rod or to a mass suspended from a coiled spring. The solutions of the two similar equations,

$$m(\mathrm{d}^2x/\mathrm{d}t^2)+h(\mathrm{d}x/\mathrm{d}t)+kx=F\sin\omega t$$

and

$$L(\mathrm{d}^2q/\mathrm{d}t^2)+R(\mathrm{d}q/\mathrm{d}t)+(q/C)=E\sin\omega t,$$

are demonstrated qualitatively. Such phenomena as resonance, transients and phase relationships can be shown. With reference to radio circuits, the analogous mechanical effects of tuning and coupling can be demonstrated. The motor producing the sinusoidal force has a special control for varying the frequency of this force and the stroboscopic effect is produced either by neon lights or by means of a disk with a hole in it. The apparatus is easy to construct and inexpensive.

20. A Demonstration Wind-Machine. Wilfrid J. Jackson and Frank R. Pratt, N. J. C., *Rutgers University, New Brunswick, N. J.*—An aluminum windmill is mounted on a shaft. This shaft is provided with a pinion bevel gear which drives two rubber-tired wheels when a fan is used to throw a blast of air against the blades of the windmill. The whole device is mounted on the two drive-wheels, together with a third wheel. If constructed so that windmills and drive-wheels of different diameters may be used and different loads carried, the device demonstrates various mechanical principles, including (*a*) the tacking of a sailboat, (*b*) the distinction between work and power, (*c*) the braking provided by the windmill as the device rolls down an incline on shutting off the fan, (*d*) slipping, by using different angles of incline and surfaces with different coefficients of friction.

21. Should One Stop or Turn to Avoid an Automobile Collision? Seville Chapman, *University of Kansas,*

Lawrence, Kans.—A man driving an automobile (at high speed) along a side road suddenly arrives at the intersection of a vacant highway. The side road does not continue beyond the intersection, there being a wall along the far side of the highway. To avoid hitting the wall, the man must either stop in the intersection, or turn. With a given force available for stopping or turning (or both), in what path should the man steer so as to travel the least distance into the highway? It is shown by a variation method that the path is a straight line in the direction of the original motion; also, if the wall is too close for the car to be stopped before hitting it, the car will have the least component of velocity perpendicular to the wall at the time of collision if the path has been straight. (The force required for turning is *twice* that for "straight-stopping.") In a similar problem regarding the question of stopping or dodging an object, unless the object subtends an angle of less than 15.0° with the line of motion, it is unquestionably better to stop. Advantages of stopping rather than turning in some other cases were shown.

22. Demonstration Lectures for High School Students. O. Blackwood, *University of Pittsburgh, Pittsburgh, Pa.*—Demonstration lectures for high school students are advantageous in that they arouse the interests of students who are at the most impressionable age; many of these students will be encouraged to study physics in high school or college and a few of the more able may become specialists. A series of lectures given last year at the University of Pittsburgh was attended by more than 1000 of the 200,000 high school students in the region. This audience, thus highly selected, was enthusiastic in its response; the results were very encouraging. In planning future lectures, we hope to include not only the new physics which tends to create awe but also lectures on the physics of common things, familiar to every boy and girl. In this way it is hoped to foster the opinion that physics can be understood by all intelligent people.

23. A Modified Ballistic Pendulum. W. H. Michener, *Carnegie Institute of Technology, Pittsburgh, Pa.*—A ballistic pendulum is provided with a crossarm that is free to rotate about a vertical axis. A rifle bullet may be fired either at the center of the pendulum causing translation only, or into the end of the crossarm causing both translation of the pendulum and rotation of the crossarm. The linear momentum acquired by the pendulum is the same in both cases, although the kinetic energy is much larger in the second case.

24. A Two-Dimensional Kinetic Theory Demonstration Model. Thomas B. Brown, *George Washington University, Washington, D. C.*—The ping-pong balls which serve as the "molecules" of this model are kept in motion in a vertical plane by a simple agitator of unique design. This plane region in which they move is 18×24 in., so that demonstrations are easily seen by a large class. The model may be used to demonstrate the random motions of molecules in liquids and gases, the pressure of a gas against a piston, the law of atmospheres, diffusion of a gas through a porous plug, Brownian movements, etc. It may also be used in the laboratory for various statistical experiments.

ATTENDANCE

The registration of those in attendance lists 113 members of the Association and 63 nonmembers. Members who registered were:

Gladys Anslow, Smith College; R. H. Bacon, Frankford Arsenal; M. Balderston, Lafayette College; H. A. Barton, American Institute of Physics; Vola P. Barton, Goucher College; B. W. Barnett, Bowdoin College; P. F. Bartunek, Rensselaer Polytechnic Institute; R. M. Bell Washington and Jefferson College; P. Bender, Goshen College; C. E. Bennett, University of Maine; H. Louisa Billings, Smith College; L. I. Bockstahler, Northwestern University; J. L. Bohn, Temple University; K. R. Brandt, Northeast High School, Philadelphia; M. L. Braun, Catawba College; G. P. Brewington, Lawrence Institute; F. L. Brown, University of Virginia; T. B. Brown, George Washington University; D. Callihan, College of the City of New York; T. J. Carroll, College of New Rochelle; Edna Carter, Vassar College; S. Chapman, University of Kansas; F. F. Cleveland, Illinois Institute of Technology; J. J. Coop, Washington College; T. D. Cope, University of Pennsylvania; J. H. Couliette, Birmingham Southern College; F. P. Cowan, Rensselaer Polytechnic Institute; R. T. Cox, New York University; S. W. Cram, Kansas State Teachers College; W. P. Cunningham, Tower Hill School; R. M. Dibert, DuBois Undergraduate Center, Pennsylvania State College; H. L. Dodge, University of Oklahoma; C. Driscoll, Central High School, Washington, D. C.; D. C. Duncan, Pennsylvania State College; R. L. Edwards, Miami University; J. D. Elder, Lynchburg College; J. A. Eldridge, University of Iowa; F. M. Exner, Columbia University; A. W. Foster, University of Western Ontario; C. R. Fountain, Peabody College; M. Katherine Frehafer, Goucher College; M. M. Garrett, Swarthmore College; R. C. Gibbs, Cornell University; G. W. Giddings, DePauw University; G. E. Grantham, Cornell University; V. B. Hall, Bucknell University Junior College; Monica Healea, Vassar College; N. Hilberry, New York University; D. M. Hill, Elizabethtown College; J. R. Hobbie, Skidmore College; W. L. Hole, Elmhurst College; F. F. Householder, University of Akron; R. H. Howe, Denison University; G. F. Hull, Dartmouth College; A. D. Hummel, Eastern Kentucky State Teachers College; A. T. Jones, Smith College; G. E. C. Kauffman, Henry C. Conrad School; J. M. Kelley, Loyola High School, Baltimore; P. M. Kendig, Schuylkill Undergraduate Center, Pennsylvania State College; P. E. Klopsteg, Central Scientific Company; H. P. Knauss, Ohio State University; K. Lark-Horovitz, Purdue University; J. Laughlin, Haverford College; D. P. LeGalley, Philadelphia College of Pharmacy and Science; H. Levene, Central High School, Philadelphia; C. C. Liljenstein, Pebble Hill School; N. C. Little, Bowdoin College; O. E. McClure, Ohio University; Louise S. McDowell, Wellesley College; Sister Anastasia Maria, Immaculata College; Sister Grace Marie, College of Chestnut Hill; F. W. Mauchly, Ursinus College; W. H. Michener, Carnegie Institute of Technology; P. A. Northrop, Vassar College; J. S. O'Conor, Woodstock College; T. H. Osgood, University of Toledo; H. N. Otis, Hunter College; F. Palmer, Jr., Haverford College; A. L. Patterson, Bryn Mawr College; J. T. Peters, Overbrook High School, Philadelphia; J. S. Rinehart, Fort Hays Kansas State College; G. D. Rock, Catholic University of America; E. M. Rogers, Mt. Holyoke College; D. Roller, Hunter College; A. Romer, Whittier College; H. H. Roseberry, Ohio University; G. Rosengarten, Philadelphia College of Pharmacy and Science; Sister Mary St. Helen, Mundelein College; H. K. Schilling, Union College; J. M. Schmidt, Hofstra College; R. S. Shaw, College of the City of New York; S. Sonkin, College of the City of New York; A. D. Sprague, Elon College; M. N. States, Central Scientific Company; G. W. Stewart, University of Iowa; R. M. Sutton, Haverford College; Sister Mary Therese, Mundelein College; E. W. Thomson, U. S. Naval Academy; J. Tobin, Belmont Abbey College; G. D. Van Dyke, Earlham College; H. E. Way, Knox College; W. Webb, Pennsylvania State College; W. S. Webb, University of Kentucky; Dorothy W. Weeks, Wilson College; M. R. Wehr, Drexel Institute; N. E. Wheeler, Colby College; M. W. White, Pennsylvania State College; L. V. Whitney, Southwestern Missouri State Teachers College; Frances G. Wick,

Vassar College; K. S. Woodcock, Bates College; R. M. Woods, University of Chattanooga; A. G. Worthing, University of Pittsburgh; I. F. Zartman, Muhlenberg College.

Annual Report of the Treasurer

Balance brought forward from Dec. 15, 1939		$3855.52
CASH RECEIVED		
Dues received[1] for 1940	$4194.50	
Dues received for 1939	20.00	
Dues received for 1941	140.00	
Grant	1500.00	
Royalties, *Demonstration Experiments in Physics*	284.39	
Membership fee for A.C.E., paid by American Institute of Physics	100.00	
Donations	26.85	
Total cash received	$6265.74	
Total deposited from 12/15/39 to 12/16/40		6265.74
Total cash available		$10,121.26
DISBURSEMENTS		
Postage and supplies	$ 208.71	
Printing	44.19	
Secretary's office expense	226.09	
Stenographer, Editor's office	648.30	
Membership fee in A.C.E.	100.00	
Editor's traveling expense	75.90	
Payments to American Institute of Physics	5391.62	
Traveling expense of A.C.E. representatives	100.00	
Discount on Canadian checks	2.86	
Journal survey articles	25.00	
Money advanced on *Demonstration Experiments in Physics*	284.39	
Certificate for Oersted Medal	7.80	
Total disbursed		7114.86
Balance on hand[2] Dec. 16, 1940		$3006.40

PAUL E. KLOPSTEG, *Treasurer*

I have audited the books of account and records of Dr. P. E. Klopsteg, Treasurer of the American Association of Physics Teachers, for the year ending December 16, 1940, and hereby certify that the foregoing statement of receipts and disbursements correctly reflects the information contained in the books of account. Receipts during the year were satisfactorily reconciled with deposits as shown on the bank statements, and all disbursements have been satisfactorily supported by vouchers or other documentary evidence.

Chicago, Illinois,
December 19, 1940.

WILLIAM J. LUBY,
Certified Public Accountant

[1] On December 16, 1940, there were 867 members in good standing.
[2] A balance of approximately $1000 is due the American Institute of Physics for the publication of the journal during 1940.

Proposed Common Date for Accepting Graduate Appointments

THE Association of American Universities, at the November, 1940 meeting, adopted a resolution recommending to its members:

(1) *that, with respect to appointments to teaching fellowships, assistantships or other positions in which it is expected the incumbent will work also as a graduate student, the member universities, in all their divisions, observe a common date before which acceptance of an offer of appointment will not be required;*

(2) *that April 15 preceding the beginning of the academic year of appointment be adopted as the common date;*

(3) *that each offer of appointment, whether formal or informal, be accompanied by a statement to the effect that no demand is made for the acceptance of this offer prior to April 15;*

(4) *that the foregoing procedure shall not be taken to apply in the case of appointments of persons to assistantships or teaching fellowships who are already enrolled in the university which is to make the appointment.*

In connection with the initiation of this proposal it should be noted, as suggested by the Association, that: (1) the choice of April 15 as the date before which acceptances of these positions are not to be requested is the date until which all fellowship appointments in the member institutions of this Association are held open; (2) under this resolution an institution may make an offer of such a position to an applicant as early as that institution may desire, provided it makes plain to the applicant that he will have until April 15 preceding the academic year of appointment to send an acceptance; (3) it will be appropriate to request of any such applicant, if at any time between the receipt of the offer and April 15 he decides not to accept the appointment, the courtesy of an immediate notification to that effect.

In the interests of uniformity and of fairness to applicants a committee representing physics department chairmen expresses the hope that this resolution will be observed generally, irrespective of membership of institutions in the Association of American Universities, and that the staff members in physics departments from which applicants are seeking appointments will cooperate by appropriately advising their students.

Post-Doctorate Research Fellowship for Woman

The fellowship, with a stipend of $1000 to $1500, will be awarded by Sigma Delta Epsilon, graduate women's scientific fraternity. Submit application and references before March 1. For application blank address Dr. Nina E. Gray, University, Normal, Ill.

RECENT PUBLICATIONS AND TEACHING AIDS

Laboratory Manuals

Experimental College Physics. Marsh W. White, Associate Professor of Physics, Pennsylvania State College. Ed. 2. 398 p., illustrated, 15×23 cm. *McGraw-Hill*, $2.75. With 10 new experiments added, the present edition of this comprehensive laboratory manual contains 74 experiments and is 35 percent larger than the edition of 1932. In the case of eight of the experiments, selected portions of two other experiments already in the manual have been combined to form a single experiment; for example, the topic of resistances and cells in series and parallel may now be covered in either a single or a double laboratory period. Many of the original experiments and diagrams have been revised, but in such a way that users of the first edition can easily adapt their courses to the second.

Advanced Textbooks

Applied X-Rays. George L. Clark, Professor of Chemistry, University of Illinois. Ed. 3. 690 p., 342 figs., 15×23 cm. *McGraw-Hill*, $6. The primary purpose of the 1926 and 1932 editions of this textbook was to portray x-rays as a great practical research tool in industry. Alhtough this purpose is retained, the author has taken advantage of the great advances in this field to provide a new treatment that is much more rigorous, integrated and quantitative than was possible in 1932. The first third of the book, dealing with fundamental principles and basic technics, has chapters on tubes, high voltage equipment, measurements of intensity and wave-length, atomic structure, chemical analysis of x-ray spectra, absorption and scattering, radiography, x-ray photochemistry, and biologic effects. The remainder of the book—433 pages—provides a detailed treatment of the x-ray analysis of the ultimate structures of materials.

Electronic Structure and Chemical Binding with Special Reference to Inorganic Chemistry. Oscar Knefler Rice, Associate Professor of Chemistry, University of North Carolina. 526 p., 91 figs., 55 tables, 15×23 cm. *McGraw-Hill*, $5. The course for which this textbook is designed differs distinctly from the traditional first-year graduate course in inorganic chemistry, for its purpose is to provide the student with a foundation in modern atomic physics and in the applications of the latter to the classification of compounds and to numerous chemical problems concerned especially with the nature of chemical binding. The treatment of modern atomic theory, which occupies the first third of the book, is relatively elementary and often semiqualitative, but doubtless adequate for the average student of chemistry who does not intend to specialize in the field.

Static and Dynamic Electricity. William R. Smythe, Associate Professor of Physics, California Institute of Technology. 578 p., many diagrams, 3 tables, 15×23 cm. *McGraw-Hill*, $6. This textbook and reference work is the outgrowth of a course which the author has given for many years and which is designed essentially to train the experimentalist in the application of electric theory and in working out from first principles even those problems that fall outside the routine types. The emphasis is therefore on the solution of a great variety of special problems, 100 of which, each selected for an important reason, are worked out in the text, while 500 more, many of them with answers, are provided at the ends of the chapters. Only the theory that has important applications is included and this is developed by the most concise methods compatible with the assumed preparation of the student. Although the mathematical methods used are relatively advanced for a course of this grade, they doubtless can be mastered with some guidance by a good student who has had undergraduate courses in mathematical physics and differential equations. Vector methods are employed; more than ordinary use is made of Bessel functions and conformal transformations; and the methods of restricted relativity are employed exclusively in treating forces between moving charges. All the magnetic theory is based on the interactions of currents or moving charges. No attempt is made to treat the theories of such phenomena as electrolytic conduction and thermionic emission, because an adequate treatment of them involves a broader background of knowledge than the average student possesses at this stage. The theory of electric machines and instruments is also omitted, on the ground that it is best treated in connection with laboratory courses. No one system of units is adopted for the book; the units used for each topic are those that seemed simplest to work with, and these are in every case indicated at the bottom of the page. Incidentally, the author found from an inspection of some 1500 equations occurring in the theoretical parts of the text that the use of rationalized units would decrease the complexity of approximately 11 percent of them, increase that of 9 percent and leave 80 percent unchanged; thus, in the theory at least, there was little to choose between rationalized and unrationalized units.

Units and Dimensions

M. K. S. Units and Dimensions and a Proposed M. K. O. S. System. G. E. M. Jauncey, Professor of Physics, and A. S. Langsdorf, Dean of the School of Engineering, Washington University. 70 p., 5 figs., 14×22 cm. *Macmillan*, $1. In the Foreword the authors say:

> The purposes of this little book are: to acquaint electrical engineers, physicists, and teachers and students of electrical engineering and physics with the properties of the new meter-kilogram-second . . . system of basic units; to describe methods for changing

from one set of basic units to another; to give reasons for the adoption of the ohm as the fourth basic unit . . . ; to describe a proposed M. K. O. S. system of basic units; and to discuss the difference between magnetic flux density (B) and magnetic field strength (H).

For the first two of these purposes the monograph is admirable and timely. It is brief, well written, and points out the numerous advantages of the mks system clearly and forcefully. The last three purposes mentioned in the Foreword amount to the championing of controversial issues concerning each of which the authors have presented one side. Several fallacies exist in the authors' arguments for the necessity of choosing a fourth basic unit. Their choice of the international ohm is a mistake, since the International Committee on Weights and Measures recommends that all electric units be established by the so-called absolute measurements, an action equivalent to giving the permeability of free space a fixed value. This change in the methods used in establishing our electric and magnetic units was scheduled to go into effect on January 1, 1940, but has been delayed because some national laboratories have not completed their measurements. When they become effective there will be no place for a standard ohm, but rather the ohm will be established by measurements such as have been made at the National Bureau of Standards. The ohm established in this way certainly is more unchangeable than any laboratory standard could be; and it is believed, from past experience, that the changes in the laboratory standard are larger than the inaccuracies in establishing the ohm by absolute measurements.

The question of dimensions is not so closely linked with standards as the authors imply. It has been pointed out by BRIDGMAN, BIRGE and others that dimensions for purposes of dimensional analysis may be chosen quite arbitrarily, although the number of primary quantities needed does depend upon the system of equations employed and upon certain assumptions regarding factors of proportionality. The authors' use of four primary quantities is proper and desirable but not necessary; a perfectly consistent system can be set up with the three primary quantities, *meter*, *kilogram* and *second*. The authors try to show that B and H are fundamentally different and, therefore, must have different dimensions. Even if we grant that B and H are fundamentally different, we need not accept the conclusion that they must have different dimensions. Examples of fundamentally different quantities that have the same dimensions are work and torque, and also Young's modulus, the shear modulus and pressure. In the Gaussian and Heaviside-Lorentz systems B and H do have the same dimensions. However, for many purposes it is desirable that B and H have different dimensions, and this is one of the advantages of the mks system; a fourth primary quantity fits into it very naturally. A fourth primary quantity must be used to distinguish dimensionally between B and H, and the use of this fourth primary quantity effects several other desirable distinctions. The ohm, which the authors propose for this purpose, has no advantage over the ampere, volt or coulomb. A definite choice is not necessary; the choice should depend on the particular problem at hand, just as in some mechanics problems it is desirable to choose force in place of mass as the primary quantity.

The authors' choice of the nonrationalized system is unfortunate. The report of the committee of the American Association of Physics Teachers states,

> The question of rationalization of mks units has been left open by international committees. Opinion seems to be rather evenly divided on the subject, with perhaps a majority of those who have studied the matter carefully in favor of rationalization. It seems to this committee that it is not so important which way the matter is decided, but that it is important to have it decided one way or the other at this time. It would be unfortunate to have two forms of the mks system come into use. We have, therefore, listed definitions only for the rationalized units.

The excellent textbooks by SMYTH and UFFORD, VIGOUREUX and WEBB, and HARNWELL employ rationalized units. A choice has been made, and we should abide by it. With the nonrationalized system, new names would have to be chosen for magnetomotive force, magnetic field strength, electric displacement and certain other quantities. In truth, as the authors of the present monograph say, rationalization eliminates the 4π in some equations but introduces it into others. But one should add that it eliminates the 4π from the equations that are most used. This monograph is well worth reading, but it should be read critically.—E. M. P.

VECTOR ANALYSIS

Vector Analysis. JAMES HENRY TAYLOR, Professor of Mathematics, George Washington University, 188 p., 34 figs., 15×23 cm. *Prentice-Hall*, $2.85. Vector analysis is treated as a branch of mathematics, rather than of physics, in this introductory textbook. Thus the applications in the book have been chosen for their illustrative value and not with regard to their importance in the field of application; and the stress throughout is on logical aspects rather than on technics and details of calculation. The presentation is not only orderly but often quite original both in outlook and in the choice of material. Considerable emphasis is placed on the theory of linear dependence and the notion of invariants with respect to a group of transformations, thus paving the way for the chapter on tensor analysis, which occupies the last fifth of the book. The book should be useful for collateral reading in physics courses.

An Introduction to Vector Analysis for Physicists and Engineers. B. HAGUE, Lecturer in Electrical Engineering, University of Glasgow. 126 p., 39 figs., 10×18 cm. *Chemical Publishing Co.*, $1.50. Based on a course of lectures given several years ago to graduate students in electrical engineering at the Polytechnic Institute of Brooklyn, this pocket-size monograph outlines the elements and applications of vector analysis most needed by the practicing engineer or experimental physicist who must read technical literature involving vector methods. The outlook adopted is mainly physical; geometrical and other purely mathematical considerations are limited to essentials; formal proofs of invariance and conditions of continuity in vector processes are replaced by appeals to physical intuition. Among the topics included are the Gauss and Stokes

theorems, the Maxwell equations, and the elementary properties of tensors and dyadics; but purely analytic topics of an advanced character, such as Green's theorem, are omitted. There are no questions or problems.

Applied Physics

Strength of Materials. Arthur Morley, formerly Professor of Mechanical Engineering, University College, Nottingham, and later H. M. Staff Inspector of Technical Schools. Ed. 9. 581 p., 260 figs., 14×22 cm. *Longmans, Green*, $4.20. In this, the ninth editoin of a standard textbook, the type has been reset, thus providing the opportunity for a more extensive revision than has been possible heretofore. Among the topics rewritten are fatigue, criterions of elastic strength, creep, metallurgical developments of ferrous metals and methods of testing. More use has been made than heretofore of elastic strain-energy for the determinations of elastic deformations. Since 1908, when the first edition appeared, 52,000 copies of this book have been printed.

Weather Analysis and Forecasting. Sverre Petterssen, Professor in Charge of the Meteorological Division, Massachusetts Institute of Technology. 521 p., 249 figs. and maps, 15×23 cm. *McGraw-Hill*, $5. This textbook for students and reference work for professional forecasters originated from a series of lectures on synoptic meteorology delivered by the author during the past five years in various technical institutions here and abroad. The treatment it provides of the physical principles and theories underlying modern methods of weather analysis and forecasting is not only authoritative and comprehensive but has the merit of being developed in such a manner as to facilitate greatly the applications to actual forecasting. Although previous training in the general principles of meteorology is not a prerequisite for understanding this book, a good grounding in physics and in mathematics through elementary calculus will be found almost indispensable.

Electric Circuits. Members of the Staff of the Department of Electrical Engineering, Massachusetts Institute of Technology. 815 p., 461 figs., 9 tables, 15×23 cm. *Wiley and Technical Press*, $7.50. A textbook prepared by the members of a departmental staff working collaboratively is no novelty; and certainly the idea of reorganizing curriculums and teaching programs has been thoroughly exploited by the educationists. But it is an event of some significance when an entire staff of a scientific department, with members having varied interests in both teaching and research, not only engages in a major educational project involving the preparation of a series of integrated textbooks but is willing to have these books published without the names of the individual authors appearing anywhere in them and to have its efforts characterized as a "research project" to reorganize a program of teaching and improve educational methods. The staff of the Department of Electrical Engineering, Massachusetts Institute of Technology, has for several years been engaged in such a project; it is revising as a unit its entire presentation of the basic technologic principles of electrical engineering, in the belief that a new synthesis of educational material in this field can be effected and a set of textbooks evolved that will have a breadth of view not easily approached by an author working individually, that will be free from the duplications and lack of balance present in an unintegrated series, and that will comprise a basic course adequate for all students of electrical engineering regardless of their ultimate specialty. The present textbook for a beginning course in *circuit analysis* is the first of this projected series; obviously, it will be examined with considerable interest by all who are concerned with the improvement of engineering education. The remaining three volumes comprising the basic course will cover *magnetic materials and transformers*, *applied electronics*, and *electric machinery*. A fifth, supplementary volume is being prepared for teachers and students who wish to pursue further and to examine more critically the ideas presented in the basic texts.

Photography

Photographic Lenses and Shutters. Richard W. St. Clair. 158 p., 99 figs., 12×17 cm. *Ziff-Davis*, $0.50. Written for the beginner in photography who is unacquainted with optics, this brief monograph presents the geometry of image formation by lenses with applications at every step, to the problems peculiar to photography. The first half, on elementary geometrical optics, emphasizes usefulness of formulas and conclusions at the expense of an understanding of the manner in which they are derived. The author evidently believes that the average beginner is interested mainly in information of a practical, or immediately useful, nature which will help him to attain the results he desires; that only later, if at all, will the amateur want to understand the underlying theory. Seen from this practical point of view the book is excellent. The second half of the book is devoted to a discussion of photographic objectives with cross-section drawings of 20 of the more common types. Several shutters are described, and technics for testing lenses and shutters are discussed. The book is well written, and the author is to be congratulated for having avoided the patronizing style affected by so many writers of popular books on photography.—W. W.

Miscellaneous Books

French-English Science Dictionary. Louis De Vries, Professor of Modern Languages, Iowa State College. 254 p., 13×18 cm. *McGraw-Hill*, $3.50. Like the German-English science dictionary by the same author [Am. J. Phys. **7**, 349 (1939)], this French dictionary of 43,000 entries is unique in that it includes terms from the agricultural, biological and physical sciences, as well as many nontechnical words. The printing and binding are good.